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AURORAL ZONE PEARL PULSATIONS

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ABSTRACT

An analysis has been made of Pc 1 band micropulsations observed in the auroral zone during one solar rotation at Flin Flon, Manitoba, August - September 1964. The Pc-1 band micropulsations were subdivided into Pearl Pulsations (PP), impulsive activity (IMP), and short irregular pulsations (SIP); this paper is concerned primarily with PP.

We have observed the following: (1) there is no correlation of PP with electron precipitation indicated by bremsstrahlung recorded at balloon altitude; (2) PP type activity occurs at the time of a sudden commencement and can have an hourly repetition of occurrence for five or six hours thereafter; (3) the K_p and A_p indices are too coarse for adequate representation of geomagnetically disturbed times when studying the dependence of PP occurrence on geomagnetic activity; (4) there may be a slight increase of PP period with increase in K; (5) PP have higher amplitudes when K values are higher; (6) Pc-3, 4 band activity may be used as a good predictor for PP occurrence, since, for days rated as disturbed by Pc 3-4 activity, there is an inverse correlation between PP and pc 3-4. For days rated as quiet by Pc-3, 4 activity, PP may occur at any time during the daylight hours; (7) PP are distributed throughout the daylight hours on quiet days while they tend to appear only within an hour or two of 1800 lmt on disturbed days; (8) observed polarization diagrams do not appear to be explained simply in terms of superimposed elliptically polarized waves as suggested by Pope (1964).

We can interpret the above observations in terms of a hydromagnetic wave packet origin for PP with the occurrence of PP dependent upon four features: (1) triggering mechanism; (2) amplification mechanism; (3) guiding along field lines; (4) transmission through the ionosphere.

AURORAL ZONE PEARL PULSATIONS

INTRODUCTION

During the period August 16 to September 20, 1964, we continuously recorded magnetic micropulsations at Flin Flon, Manitoba, geomagnetic coordinates (63.6 N, 314.8). The purpose of these recordings was to obtain information on the characteristics of micropulsations at these latitudes and examine the possibility of a relationship of micropulsations to electron precipitation. Simultaneous information on electrons was obtained from a number of high altitude balloon flights carrying x-ray detectors.

EXPERIMENTAL APPARATUS AND DATA REDUCTION

A schematic diagram of the magnetic micropulsation system used is shown in Figure 1. The currents induced in large induction coils were amplified, filtered and recorded on strip chart recorders at speeds of 1 or 4 in/min. Typical Pc-1 band filter characteristics are shown in Figure 2.

Data reduction was done in two parts. The records were first logged in 10-minute intervals with respect to the occurrence, amplitude, and period of PP (Pearl Pulsations). If no PP occurred, the amplitude of the background was recorded. In the second step selected high quality samples of PP were digitized and placed on punched cards.

EXPERIMENTAL RESULTS

Correlation with electrons. During the recording period six high altitude balloon flights were made in an attempt to observe electron microbursts. On only one flight (September 8) was there sufficient electron precipitation to justify data reduction. On all flights except this one some

PP occurred during the flight and at times of no electron precipitation. During the one flight when considerable electron precipitation occurred, particularly the microbursts described by Anderson (1964), there were no PP detected.

This result is in general agreement with the lack of correlation between PP and other geophysical phenomena discussed by many observers. However, Troitskaya (1961) has suggested an association of IPDP (Intervals of pulsations of diminishing period), with balloon observations of x-rays. Tepley and Wentworth (1962) also suggest such a relationship based on balloon and riometer observations. These examples seem somewhat anomalous, however, for both were made during sudden commencement events, which correspond to a minority of pearl occurrences. Campbell (1964) has made extensive observations of PP in the auroral zone during periods of simultaneous balloon flights. He sees no correlation between PP and x-rays, even during periods of intense electron precipitation. Thus our results are in agreement with the most detailed observations made to date.

For the flight of September 8 an attempt was made to determine whether the amplitude of the Pc-1 band background was related to the incident electron fluxes. Figure 3, based on 10-minute averages, shows no indication of a relationship on a gross scale. A more detailed comparison based on one-minute averages is given in Figure 4 for the most active hour of the flight. It is clear that there is no detailed correspondence. A further attempt was made to determine whether a difference existed in the Pc-1 records between the two most active and the two quietest hours of this flight. The results do not indicate any significant difference. Close visual examination suggests that the magnetic record, for this period band, may be slightly more erratic during electron precipitation, but not in any significant or easily

described fashion.

Correlation with A_p index. Preliminary examination of magnetograms obtained at Flin Flon during the recording period, as well as activity in the Pc-3, 4 band, seemed to indicate that PP occur during magnetically quiet times. Figure 5 compares the daily magnetic A_p index to the daily total of the number of occurrences of PP in ten-minute intervals. Half-hour occurence data published by the Geophysical Institute, University of Alaska (1964) for the same period is also shown. It should be noted that there is little correspondence between the Flin Flon magnetic and College telluric results, despite the fact that Flin Flon and College are separated by only 1° of magnetic latitude (Flin Flon 63.6°, College 64.7°. They are, however, separated by 58° of magnetic longitude). It is also apparent that there is little general correlation between the occurrence of PP at Flin Flon and College and the A_p index. However, a predominant enhancement of PP activity occurs in both the Flin Flon and College data on September 6. In the period following this date, there appears to be an inverse relation between A_p and the number of occurrences of PP. This is particularly evident in the Flin Flon data. The linear correlation coefficient between A_p and the number of occurrences for the period prior to September 6 was found to be -.2, while that for the later period was -.7. The coefficient for the second period is quite high having only a 1% probability of occurring by chance assuming a Gaussian distribution of errors. This result is of particular significance when it is noted that a sudden commencement (sc) occurred at 1355 Local Time on September 6.

There exists considerable justification in the literature for the assumption of a relationship between sudden commencements and pearl pulsations. Troitskaya (1961) noted that PP were an element of the microstructure

of magnetic storms. Tepley and Wentworth (1962) observed 6 cases of PP associated with sc's, out of 30 possible. Wentworth (1963) using several year's data, statistically established an enhancement of PP on the day of a magnetic storm, and a general increase in PP during the following week. Heacock and Hessler (1965) have performed a statistical analysis of the relation of PP occurrences and sc's. They note an association about 50% of the time for sc's occurring at all times of day. For sc's occurring near times of peak PP occurrence the association is 80%, and for sc's near local noon there is essentially a 100% correlation. In addition they note a suggestion of an inverse correlation of K_p and PP occurrence following sc's.

Sudden Commencement Event of September 6, 1964

In view of the apparent relation discussed above between PP activity and the A_p index following the sudden commencement, it seems important to examine this event in more detail. Records in both the Pc-1 and Pc-3, 4 bands show interesting substructure which may have some bearing on a theory of the PP production mechanism. It should be noted that records taken for the Pc 3, 4 bands were sensitive to PP events of large amplitude, since the limits of the band pass filter used were 1 - 100 sec. period.

On the day of the sudden commencement event, 0-2400 CST, September 6, 1964, there were three major enhancements of activity in the Pc-1 band as shown schematically in Figure 6. These rose from a background of about 50 milligamma to over 300 milligamma. The times of onset of these three events are separated by approximately 6 hours, the last coinciding with the sudden commencement at 1355 CST. The first event (0210 CST) was about an hour in length and had no associated PP. The second event (0800 CST) lasted 3 hours and had some associated PP. The PP occurring at the onset of this event had a period of about 3.0 sec. and that at the end about 1.5 sec.

The third event began at the sudden commencement and lasted for approximately six hours. Interpretation of the record with regard to the presence of PP activity is quite difficult as there is no well defined envelope. However, the periods are the same as PP, and as the event progresses the envelope becomes more clearly defined and pearl-like. On this basis an examination of the records shows that PP began about 15 minutes prior to the sudden commencement with a gradual transition from short irregular pulsations of 4 sec. period to pearl-like signals of 1.5 second period. Coincident with the sudden commencement, there was an order of magnitude enhancement of erratic 4-second period activity, with a suggestion that the shorter period PP activity was superimposed. After twenty minutes the signal faded to 100 milligamma. One hour after the SC (1450) there occurred a second comparable enhancement, but of the 2-second period activity. After twenty minutes this again faded into the 4-second background. A third and fourth 20-minute enhancement of 2-second activity occurred at 155 and 1650. This hourly recurrence pattern continued for two more hours, with slight enhancement of the 4-second activity, where however the final two events assumed modulation envelopes characteristic of PP activity.

The pattern of occurrence of pearl-like activity on five successive hours following the sc may be significant. In particular it suggests the possibility of particles drifting around the earth with a period of about one hour. However, such a drift period is incompatible with the production mechanism suggested by Cornwall (1964) involving 500 kev protons at 4 earth radii. Drift periods for these particles are of the order of 100 seconds. It would be of considerable interest to make a detailed comparison of the Flin Flon and College records to determine whether a similar pattern is observed in the College data. It would be quite important if the onset

times at College were delayed by a factor corresponding to the difference in longitude between the two stations. This would verify the suggestion of a drift phenomenon and explain the periodic fluctuation in the production mechanism.

Particles drifting about the earth as a possible origin of PP have been considered by a number of authors. However, the periods involved are of the order of one minute rather than one hour. Jacobs and Jolley (1962) observed a westward drift of 15° per hour, suggesting a pattern of occurrence fixed with respect to the sun. Heacock (1963) attempted to interpret Alaska data in terms of a fixed spiral pattern of PP occurrence. Examination of data for November 22, 1961, published in this latter paper suggests on one occasion a series of hourly occurrences of PP similar to that discussed in this paper. In general this hourly repetition of pearl-like events does not seem to have been examined previously.

AVERAGE CHARACTERISTICS OF PP EVENTS FOLLOWING THE SSC

The average characteristics of pearl activity following the sudden commencement magnetic storm of September 6 were examined. The results are shown in Figure 7. As discussed above, the inverse correlation between the A_p index and the occurrence of PP stands out clearly. There also appears to be a general increase in the period and amplitude of PP for several days following the SSC for the few PP events which occurred. This is followed by a considerable decrease reaching a minimum on the fifth day, with a slow recovery towards average in the next five days.

Since this was the only magnetic storm which occurred during the recording session, it is not known whether or not this is a typical example. An attempt was made to find similar characteristics in College PP data. No

such systematic behavior was noted, even for the same event. Comparison of the Flin Flon and College data below indicates that the College telluric system is only about half as sensitive as the system used in this experiment. This fact may account for the lack of agreement of the Flin Flon and College data in this respect.

Statistical Characteristics of PP

General:

Information obtained from the logging of the Flin Flon records has been processed on IBM tabulating machines and average characteristics of PP determined. In addition data published by the Geophysical Institute, University of Alaska, has been handled in the same fashion. The data has been normalized whenever possible and the results expressed as relative frequency or probability of occurrence. These terms are loosely defined as

$$\text{Probability of occurrence} = 100 \frac{\text{Number of occurrences}}{\text{Number of possible occurrences}}$$

It should be noted, however, that no allowance has been made for the bias introduced due to the persistence of a particular characteristic in a lengthy pearl event. For example, on August 25, PP activity was observed during 71 consecutive 10-minute intervals. If by some set of circumstances the amplitude of PP activity were constant during this entire event, this one lengthy event would have considerable weight in any final averages.

The relative frequency with which pearl events of various period occurred in the intervals August 20 - September 16 at Flin Flon and January 1 - July 1 at College are shown in Figure 8. The ranges of periods observed were mainly between 1 and 5 seconds. There is considerable difference in the two distributions, with the median periods being about 3.1 seconds at Flin Flon and 1.8 seconds at College. The similarity of the Flin Flon distribution to

the characteristics of the filter pass band should be examined. As shown below, the majority of PP events observed are of low amplitude. The rapid increase in attenuation (7-12 db) exhibited by the filter above 2.0 seconds period suggests that a number of PP events in this range may be reduced in amplitude below the constant background of short irregular pulsations. Hence the lack of agreement with the College data may possibly be instrumental for periods shorter than 2 seconds. However, the general trend of the Flin Flon data in the region 2.0 - 3.0 seconds, in which attenuation is almost constant, does imply a peak at 2.7 seconds. Without detailed knowledge of the College pass band, no definite statement can be made concerning the significance of the differences in the two distributions.

The frequency distribution of observed PP amplitudes is shown for Flin Flon and College in Figure 9. Both distributions show approximately exponential fall offs with amplitude. Twenty percent of the PP events observed at Flin Flon had amplitudes between 25 and 50 mγ, with the largest amplitude event observed being 800 mγ . The low probability of observing PP less than 25 mγ at Flin Flon is not instrumental. The system noise level was approximately one-half milligamma. Instead this result is a consequence of the steady noise background of short irregular pulsations. Typically these have an amplitude of 10 - 20 mγ during quiet times. As a consequence, it becomes very difficult to identify a PP event on a amplitude time recording. A comparison of the two curves suggests that College telluric signals of 10 mv/km are comparable to 100 mγ magnetic signals.

The times of occurrence of PP are highly dependent on local time as shown in Figure 10. On the average PP were observed during 17% of the possible 10-minute intervals at Flin Flon. The most active period was 1400 - 1500 lmt with PP occurring 50% of the time. By comparison the most active period

at College was 1500 - 1600 lmt with PP 25% of the time. The difference in the maximum frequency of occurrence at the two stations suggests that the equipment at Flin Flon was considerably more sensitive than that at College.

The period of PP also appears to be a function of local time as shown in Figure 11 for both Flin Flon and College. A minimum period occurs before sunrise and a maximum period after sunset.

There is some suggestion of a similar local time dependence in the amplitude, at least for Flin Flon. There is a definite enhancement of amplitude near the middle of the day for both locations as the data of Figure 12 indicate. It is interesting to note that the enhancement at College follows (in local time) that at Flin Flon by about two hours. Clearly the effects of geomagnetic latitude and longitude need to be evaluated.

Correlation with K indices.

An attempt was made to correlate the occurrence of PP during a three-hour interval with the value of the magnetic K_p index. When all data was taken into consideration and normalized, it was found that the probability of occurrence of PP at Flin Flon or College was not a function of K_p. This should be contrasted to the more local index K_{co} at College which shows a general decrease in the probability of occurrence with increasing K_{co}. This is shown in Figure 13, for which no PP events were observed at College for $K_{co} > 5$. It is not clear whether the apparent enhancement of PP occurrence for $K_p = 6$ at College is real or simply reflects poor statistics.

Although the occurrence of PP does not seem to depend on K_p, it is possible that some other characteristics of PP does. To examine this possibility, the data was separated into groups depending on the value of K_p (K_{co} at College). It was found that the time of occurrence of PP does

depend on K as shown in Figure 14. For K = 0 the occurrence is rather well distributed throughout the day with a broad maximum about local noon. For K = 1 the probability of occurrence in the morning is slightly decreased, while there is a slight enhancement in the afternoon. This characteristic is still more evident for K = 2, particularly in the Flin Flon data. For K = 3 there is insufficient data from Flin Flon. However, the College data verifies the trend as shown for K = 3, 4, and 5. In summary, we note that as K increases, the peak probability of occurrence of PP comes later and later in the afternoon; that the times of occurrence of PP becomes more and more limited; and that the probability of occurrence is considerably enhanced at the most probable time of occurrence.

Figure 15 indicates a very slight dependence of period on the K index. There appears to be a tendency for longer period events to be associated with higher values of K. Figure 16 seems to indicate a more significant dependence of amplitude on K showing an association of higher amplitudes with higher K values. In addition it was found that for all values of K, there is an association of longer periods with higher amplitudes.

Quality of PP.

During the logging procedure a quality figure was assigned to each 10-minute interval during which PP occurred. This was based on a four point scale with one corresponding to the lowest, and four to the highest quality PP events. This quality figure was determined subjectively on a basis of the degree of uniformity and regularity of the fundamental oscillation and its modulation envelope. If PP are caused by hydromagnetic waves propagating along field lines, then a high quality figure may indicate that the particular event is associated with field lines originating near the recording station. It was found that highest quality PP events tend to occur earliest in the

local day and have more limited ranges of periods and amplitudes. This is illustrated in Figures 17, 18 and 19.

Polarization of Pearl Pulsations:

Selected three-minute samples of well defined PP events were digitized at intervals of 0.75 seconds and placed on punched cards. This data was read into a computer and broken into five 37.5 second segments per sample. Initial computer output included for each segment, a plot of the azimuth of the magnetic perturbation vector as a function of time, and a scatter diagram representing the locus of positions of this vector in the horizontal plane. A rough ellipse was drawn to include almost all points, and its azimuth from magnetic north and axis ratio measured. The average direction of rotation was determined for the segment by counting the number of clockwise and counter-clockwise rotations. The average azimuth and axis ratio for the sample was obtained by taking the average of the results for the five segments. A measure of the variability of these two quantities was found by determining the standard deviations of the five determinations of each quantity from their averages. Data samples were taken from as many hours, on as many days as was possible. Twenty samples have been studied in this fashion. Following the preceding analysis, the computer program was modified to include a least squares analysis of the ellipse characteristics. These were computed such that half the data points fell inside the resulting ellipse. Seventeen additional data samples were subjected to this analysis.

From this information it is possible to conclude that there is a tendency (two to one) towards predominately clockwise rotation (right circularly polarized for a downward propagating wave viewed along the wave normal). Also that there is a tendency for the azimuth of the polarization ellipse to be oriented approximately 35° east or west of magnetic north. The latter is

illustrated in Figure 20. Beyond these facts there appears to be no obvious systematic behavior. The direction of rotation does not depend on azimuth, time of day, or period of oscillation in any apparent fashion. Neither does the azimuth seem to depend on time of day or period.

This lack of systematic behavior may possibly be accounted for in one of the following ways. One explanation would be that irregular and diurnal variations of ionospheric characteristics are so great that systematic effects in the PP polarization ellipse are washed out. A second possibility may be related to the fact that PP pulsations are not necessarily incident normally on the earth, so that the observed ellipses are a projection into the horizontal plane. As the angle of incidence changes the azimuth of this projected ellipse also changes. (Our future studies of PP polarization will include continuous monitoring of all three magnetic components on magnetic tape. Analog techniques of data reduction will permit a more efficient utilization of available data. In addition ionospheric parameters will be available from local ionosonde stations. These improvements may result in an understanding of the observed characteristics of PP polarization ellipses.)

In addition to the above, an attempt was made to determine whether the detailed characteristics of the polarization ellipses were similar to those suggested by Pope (1964). A 10-minute sample of well defined pearls was examined in 12-second segments. The azimuths of the resulting ellipses were constant during the entire period within $\pm 2^{\circ}$, and the ratio of major to minor axis remained almost a constant 5.0. Linear polarization developed during one segment of the record, but no "beating ellipse," with continuous changes in eccentricity, or switches in the direction of the major axis occurred. This relative constancy of azimuth and ellipticity is illustrated, for the 10-minute sample, in Figure 21. The characteristics as determined by

small segments of the record persisted during a period of at least 30 minutes following the above 10-minute segment.

In contradiction to this behavior one case has been examined in which the azimuth of the polarization ellipse changes over 90° in less than one second. A detailed examination of the records shows that this is a consequence of an approximately 90° phase shift in the North-south component of the magnetic field. About thirty seconds later a similar variation returns the azimuth to the original direction.

Both these results are in disagreement with the suggestion by Pope (1964). In fact there are good theoretical reasons to doubt Pope's basic assumptions - that the polarization ellipses due to two different rising tones would have major axes with different azimuths. If pearl pulsations are a result of the proton cyclotron resonance mechanism suggested by Cornwall (1965), then each rising tone should be a left circularly polarized wave when incident on the ionosphere. The effect of the anisotropic ionosphere will be to introduce a right circularly polarized component, which produces elliptical polarization at the surface of the earth. There is not, however, sufficient frequency difference between the two tones for the resulting elliptical polarizations to be different in any significant respect.

Correlation with Pc-3, 4 Band Activity

We have seen that the probability of occurrence of PP is not related to the K_p index, but that the time of occurrence of PP and possibly the period of PP depend upon the K_p index. It is entirely possible that K_p, being a mean three hourly range index, is too coarse a measure of geomagnetic activity. As an alternate measure, one might use Pc-3, 4 band activity (10 - 150 sec. period). To investigate this possibility we have prepared Figure 22. From this figure we note the following:

1. a. Pc-3, 4 band activity (including Pi-2) on slightly disturbed days ($0 \leq \sum K_p \leq 15$) peaks strongly near 0100 local time and is generally strong between 2300 and 0500.

   b. For disturbed days ($2 \leq K_p \leq 3$), PP activity is extremely low whenever Pc-3, 4 activity is strong. Comparison of curves C and D reveals very nearly an inverse correlation.

2. a. Pc-3, 4 band activity on quiet days ($\sum K_p < 15$) peaks weakly at about 0100 and 0430, corresponding to peaks on disturbed days, but also exhibits a broad peak over the hours 1200 - 1800. The peak at 0100 corresponds to Pi-2, that at 0430 corresponds to some spectral overlap from the Pc-5 band, and the broad afternoon peak corresponds to the usual Pc-3, 4 diurnal peak. Reference to articles by Saito (1964) and Romana and Cardus (1962) has facilitated these identifications.

   b. PP activity during quiet days ($0 \leq K < 1$) occurs generally throughout the day from 0600 to 1800 and there does not appear to be any simple correlation with Pc-3, 4 activity. Apparently the magnetic activity is sufficiently low to permit observation of PP whenever a driving mechanism exists.

3. The frequency of occurrence of PP for all days does not correlate in detail with Pc-3, 4 activity. Generally the PP activity is lowest when Pc3, 4 band activity is highest between the hours of 0200 and 2000. The PP occurrence curve for all days corresponds reasonably with that found for College by Heacock and Hessler (1965). For this type of study, the Pc-3, 4 activity seems to be a much finer measure of geomagnetic activity than the K index. It should be appreciated that all of the above deductions apply to an auroral zone station.

DISCUSSION

Correlations.

Heacock and Hessler (1965) have noted that "ssc is the only geophysical phenomenon for which a relationship to pearls has been conclusively established." To this comment we would like to add the following which pertain to auroral zone observations:

1. There is no correlation of PP with electron precipitation.
2. PP type activity occurs at the time of a sudden commencement and can have an hourly repetition of occurrence for five or six hours thereafter.
3. The K_p index is too coarse for adequate representation of geomagnetically disturbed times when studying the dependence of PP occurrence on geomagnetic activity, but the occurrence of PP is clearly related to the local K index.
4. There may be a slight dependence of PP period on K, longer periods being associated with higher values of K.
5. PP have higher amplitudes when K values are higher.
6. The period of PP increase through the local day from a minimum before sunrise to a maximum at sunset.
7. The time of occurrence of PP is clearly related to the K index. For low K, PP are distributed throughout the daylight hours, with a peak about noon. As K increases the occurrence time shifts to peak at 1800 lmt and in fact to be redistributed to about a three-hour interval around 1800 lmt by the time local K reaches 5.
8. Pc-3, 4 band activity may be used as a good predictor for PP occurrence, since, for days rated as disturbed by Pc-3, 4

activity, there is an inverse correlation between PP and Pc-3, 4. For days rated as quiet by Pc-3, 4 activity, PP may occur at any time during the daylight hours.

The above correlations may very well be of importance in deducing the mechanism for PP production. Before discussing the significance of these features in relation to source mechanisms, we would like to add one more conclusion, i.e., that the polarization of pearls which we have observed cannot be derived from any simple mechanism of the superposition of two rising tones, as Pope suggests. Nor does Pope's theory seem consistent with Cornwall's theory of the origin of PP as the result of a proton cyclotron resonance mechanism.

Interpretations.

The most recent suggestions of mechanisms responsible for Pearl Pulsations are hydromagnetic in nature and very similar to those suggested for VLF emissions. An examination of these suggestions shows that there are four major problems to be studied:

1) transmission of PP through the ionosphere;
2) mechanism for guiding hydromagnetic wave packets along field lines;
3) mechanism for amplification of PP in a dissipative medium; and
4) source of magnetic disturbance which triggers the hydromagnetic wave packet.

The most likely explanation of PP seems to be that hydromagnetic radiation given off by recently trapped particles is amplified by a cyclotron instability in the plasma, is then guided along a field line due to the nature of the particular hydromagnetic wave mode, and is attenuated in passing through the ionosphere. At the present time little is known of the temporal behavior of any of the aspects of this problem. As a consequence it is not obvious how

the characteristics of PP observed in this experiment are related to the model outlined above. Possible interpretations of some of the observed facts are given in the following paragraphs.

One possible interpretation of the average characteristics of PP following the SSC Figure 7 can be based on attenuation. It is assumed after Akasofu (1964) that high values of the A_p index are caused by the presence of auroral electrojets. In particular it is assumed that particle precipitation during "stormy" times causes enhanced ionization in the auroral ionosphere. The low probability of occurrence of PP during times of high magnetic activity following the SSC is thus attributed to attenuation in the lower ionosphere. The initial increase in period is accounted for by the fact that shorter periods are attenuated more than longer periods. The following interval of smaller than average period would then result from enhanced transmission during times of relatively little disturbance.

The initial increase in amplitude is not easily interpreted in terms of attenuation, but is probably due to a stronger source mechanism. However the days of lower than average amplitude may be explained by noting the distribution of amplitudes of PP events in Figure 9. This distribution is peaked at very low values. Thus as attenuation disappears with the magnetic disturbance, a large number of low amplitude signals are transmitted and weight the average heavily.

The contrasting dependence of PP occurrence on the local K index and the world-wide K_p index (Figure 13) may also be interpreted in terms of attenuation. We assume as above that higher K values are indicative of enhanced ionization. If this is the case then the decreasing probability of PP occurrence with increasing K index, indicates that fewer PP events are transmitted through the ionosphere during <u>locally</u> disturbed times. The fact that a

similar dependence on K_p does not occur is probably related to the fact that PP occurrence is not generally a world-wide phenomenon (from local time dependence). PP are likely to be attenuated only when there is local magnetic disturbance related to enhanced ionization. The propagated influence of magnetic disturbance from other regions (as indicated by high K_p) should have little effect on local transmission of PP.

The diurnal variation of PP period may possibly be explained in terms of attenuation. For a given electron density the ionosphere is more transparent to longer periods. Increasing the electron density moves the cut off to shorter periods (Greifinger and Greifinger, 1965). From this point of view the shortest period PP activity would be just before sunrise. The observed period should then increase throughout the day to a maximum sometime in the afternoon.

At the present time there is no adequate experimental justification for the attenuation hypothesis suggested above. In fact Campbell (personal communication) has found no correlation between the occurrence of PP activity and any normally measured ionospheric parameter. Nevertheless there is still good reason to expect attenuation of PP activity in the ionosphere. Attenuation of P_c-1 band micropulsations is strongly influenced by neutral particle - positive ion collisions in the E layer. Ionospheric parameters are normally measured at much higher frequencies where the ionosphere may be treated as a lossy electron gas and where neutral particles are of little importance. Thus the observational fact reported by Campbell that there is no correlation between PP activity and normally measured ionospheric parameters is not too surprising.

The preceding interpretation in terms of attenuation is only a tentative suggestion. It is almost certain that equal or greater control of PP

characteristics arises due to the properties of the amplification mechanism. Theoretical analysis of this possibility is now being carried out.

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LIST OF ILLUSTRATIONS

Figure 1. Schematic diagram of magnetic micropulsation system used for studies made in the lower Pc-1 band.

Figure 2. Attentuation as a function of frequency for a typical band pass filter used in recording the Pc-1 band.

Figure 3. Comparison of Pc-1 amplitude in milligama as a function of local time with 15-20 KEV x-ray counting rate.

Figure 4. Detailed comparison of x-ray counting rate and amplitude of Pc-1 band micropulsations as a function of time.

Figure 5. Comparison of occurrences of pearl pulsations at College and Flin Flon with magnetic A_p index for period August 20 - September 16, 1964.

Figure 6. Amplitude of Pc-1 band oscillations showing sudden commencement effects at 1955 UT September 6, 1964.

Figure 7. Average characteristics of pearl pulsations following sudden commencement magnetic storm of 1944 UT September 6, 1964, observed at Flin Flon, Manitoba.

Figure 8. Relative frequency of occurrence of various periods of pearl pulsations as a function of period for indicated intervals, Flin Flon and College data.

Figure 9. Frequency of occurrence of various amplitudes as a function of amplitude for indicated intervals, Flin Flon and College data.

Figure 10. Frequency of occurrence of pearl pulsations as a percentage of possible occurrences plotted as a function of local time for indicated intervals, Flin Flon and College data.

Figure 11. Average period of pearl pulsations observed during indicated intervals as a function of local time for Flin Flon and College data.

Figure 12. Average amplitude of pearl pulsations observed during indicated intervals as a function of local time for Flin Flon and College data.

Figure 13. Percentage of intervals having a given value of the magnetic K index during which pearl pulsations occurred.

Figure 14. Probability of occurrence of pearl pulsations during a given hour having a specified magnetic index K, as a function of local time.

Figure 15. Percentage of total number of pearl pulsation events occurring during intervals of given K index which have a specified period.

Figure 16. Percentage of total number of pearl pulsation events occurring during intervals of given K index which have a specified amplitude.

Figure 17. Probability of occurrence as a function of local time and quality factor.

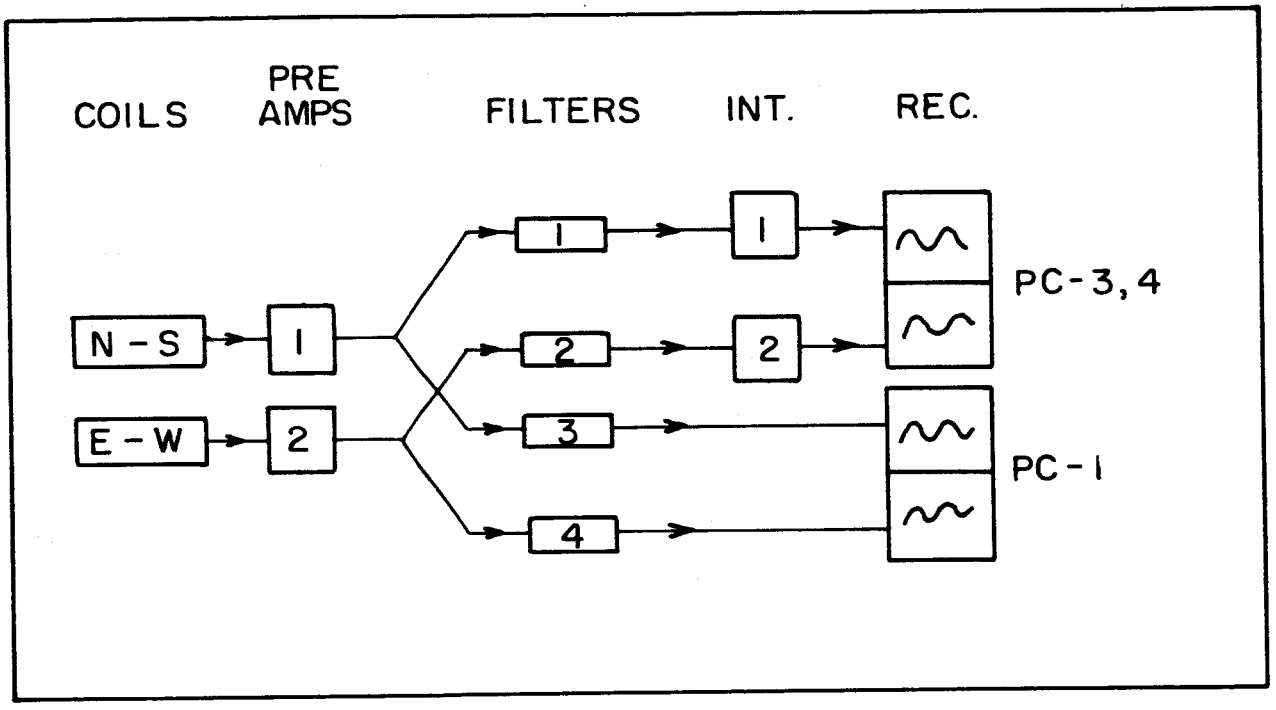
Figure 18. Probability of a given amplitude as a function of pearl envelope quality factor.

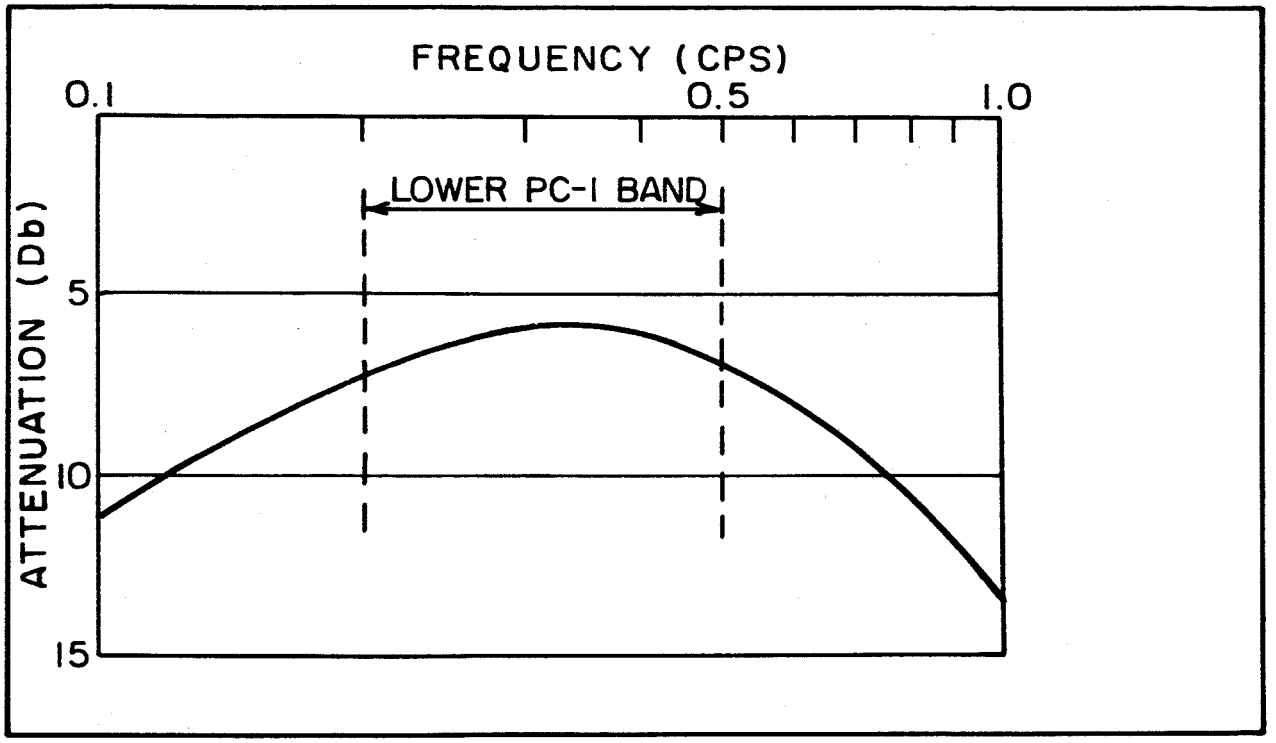
Figure 19. Probability of a given period as a function of pearl envelope factor.

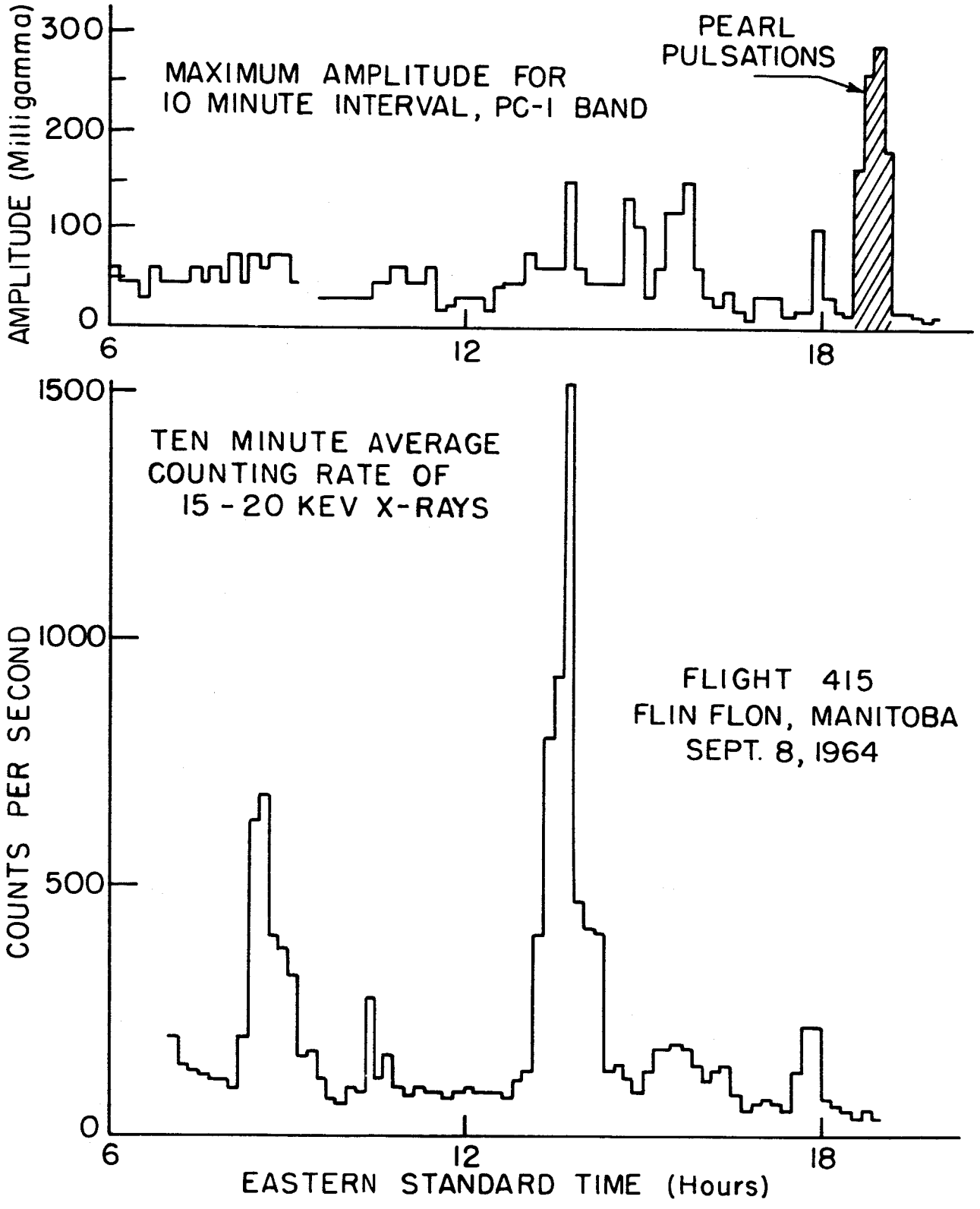
Figure 20. Distribution of azimuths and major to minor axis ratio for pearl pulsation polarization ellipses.

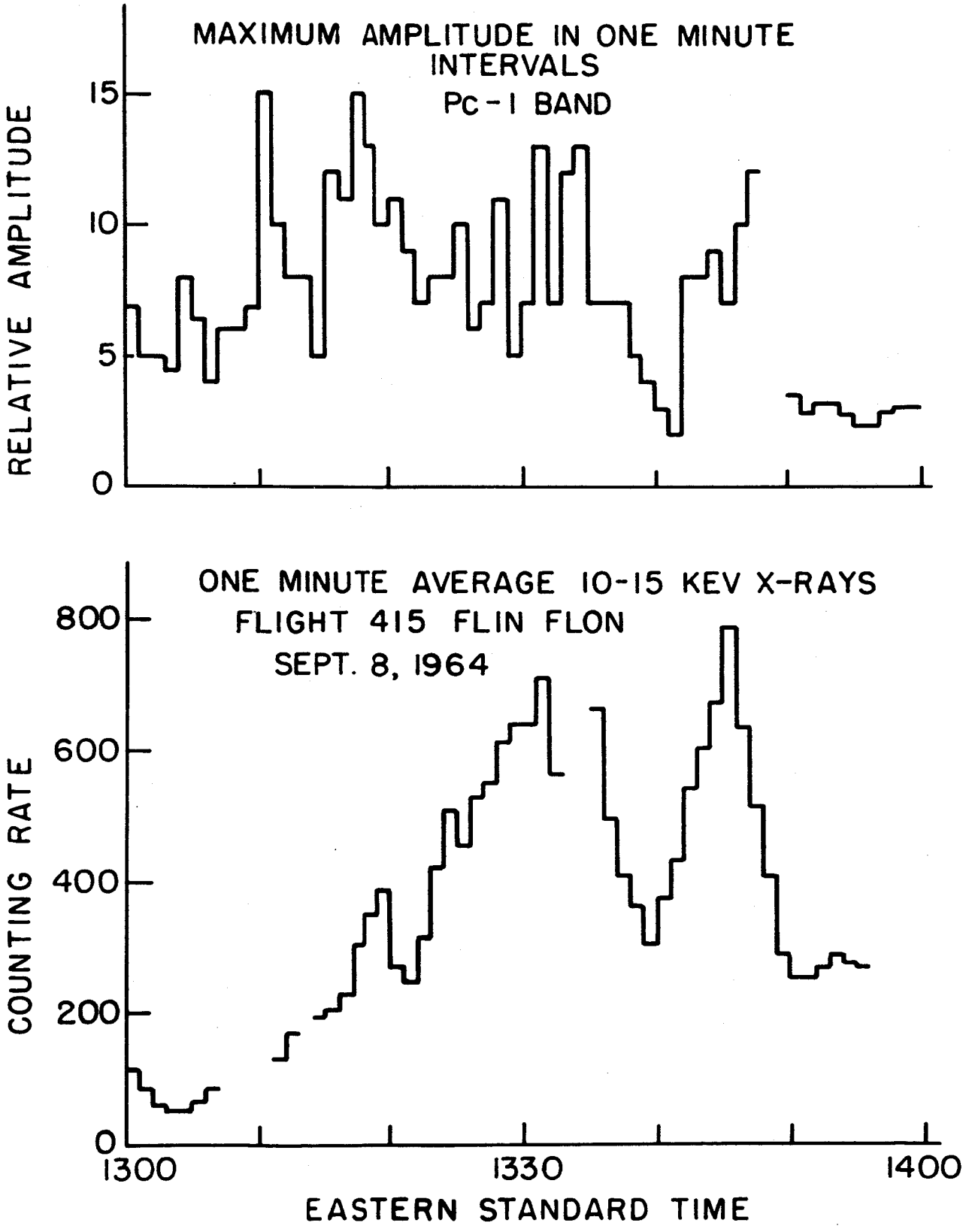
Figure 21. Comparison of the occurrence of pearl pulsations with the amplitude of Pc-3, 4 oscillations as a function of local time for magnetically quiet and disturbed times.

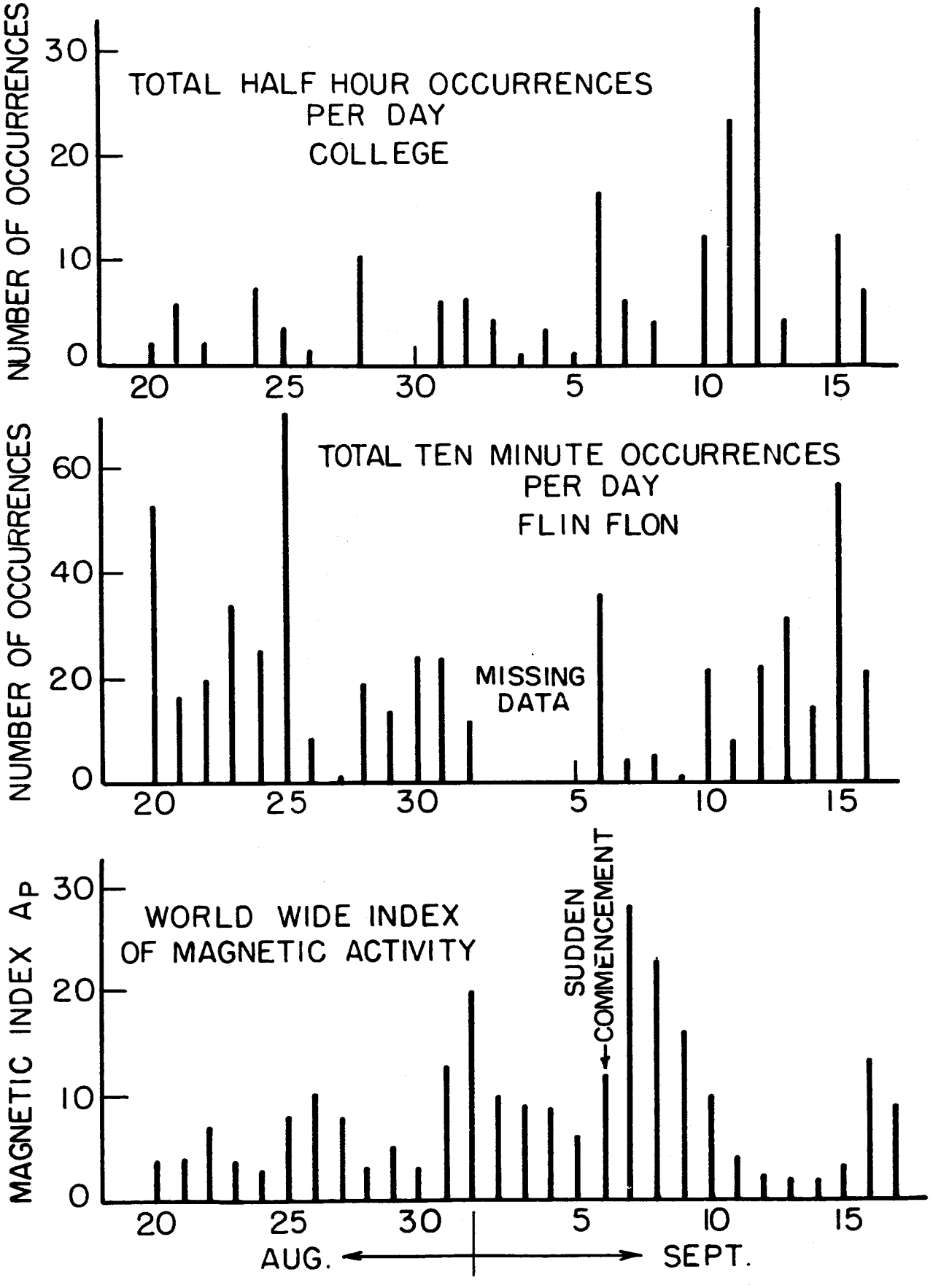
Figure 22. Comparison of the occurrence of pearl pulsations with the amplitude of Pc-3, 4 oscillations as a function of local time for magnetically quiet and disturbed times.

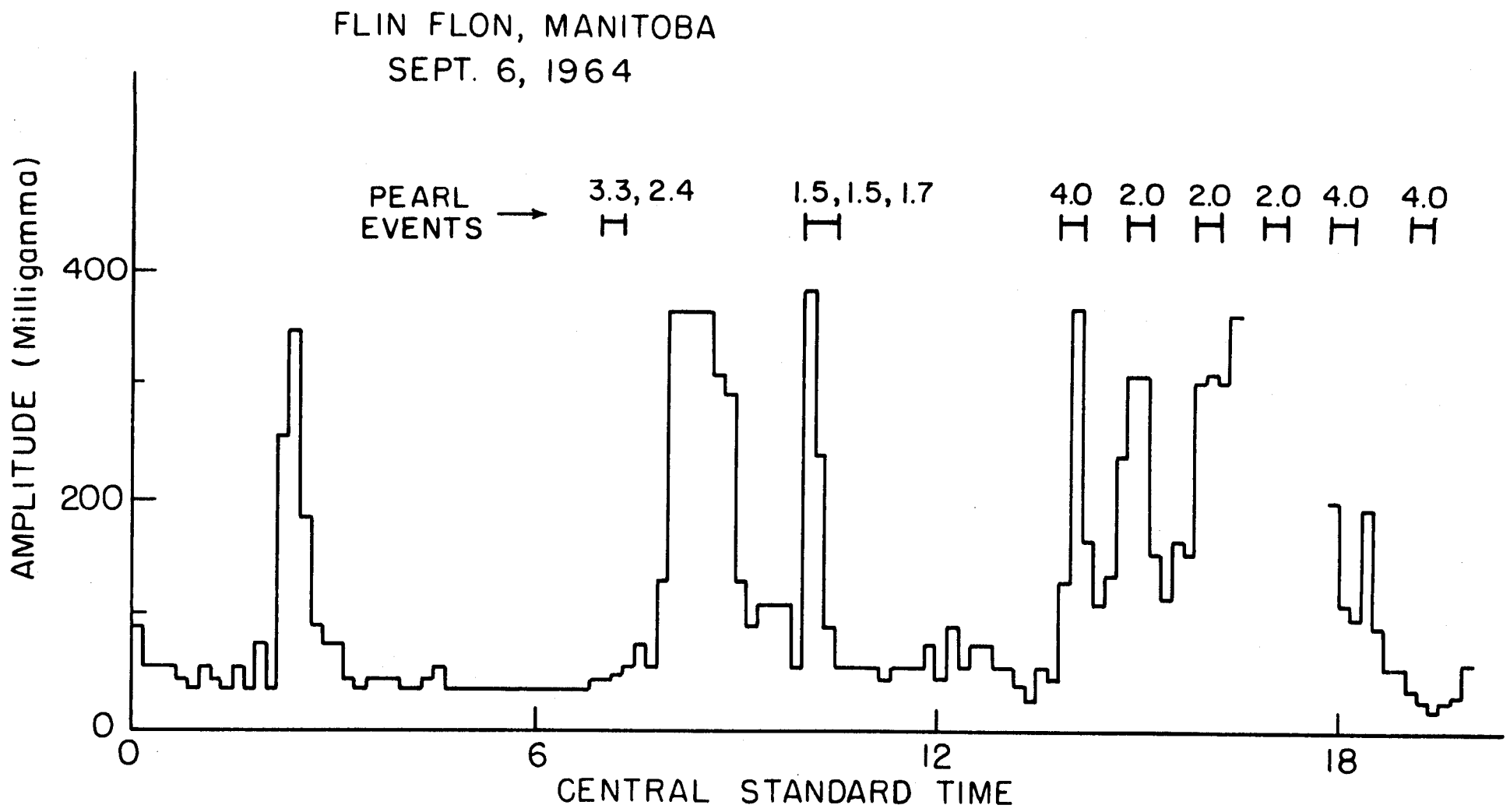

COILS
PRE AMPS
FILTERS
INT.
REC.
N - S
E - W
1
2
1
2
3
4
1
2
PC - 3, 4
PC - 1

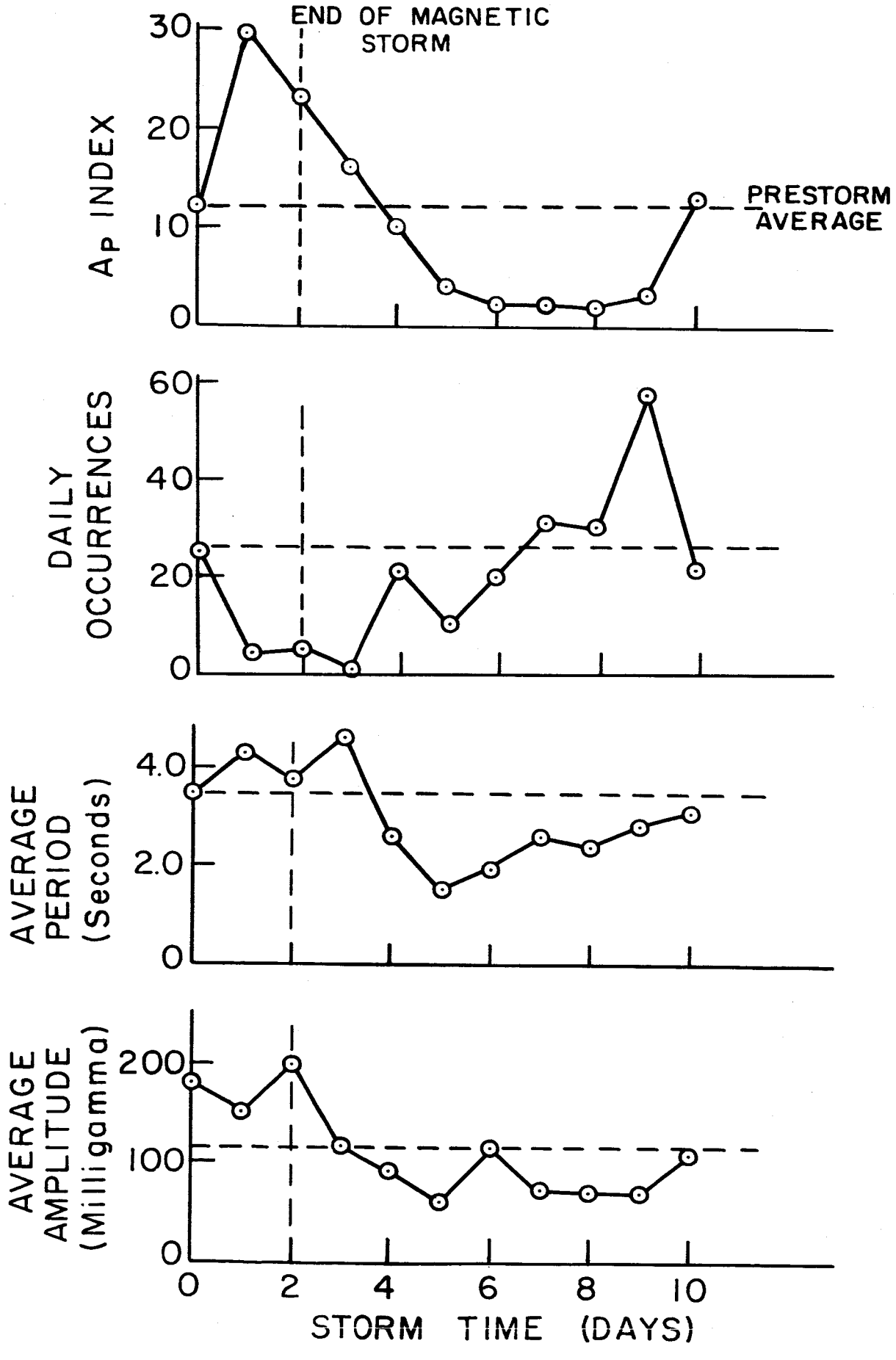

FREQUENCY (CPS)
0.1
0.5
1.0
LOWER PC-1 BAND
ATTENUATION (Db)
5
10
15

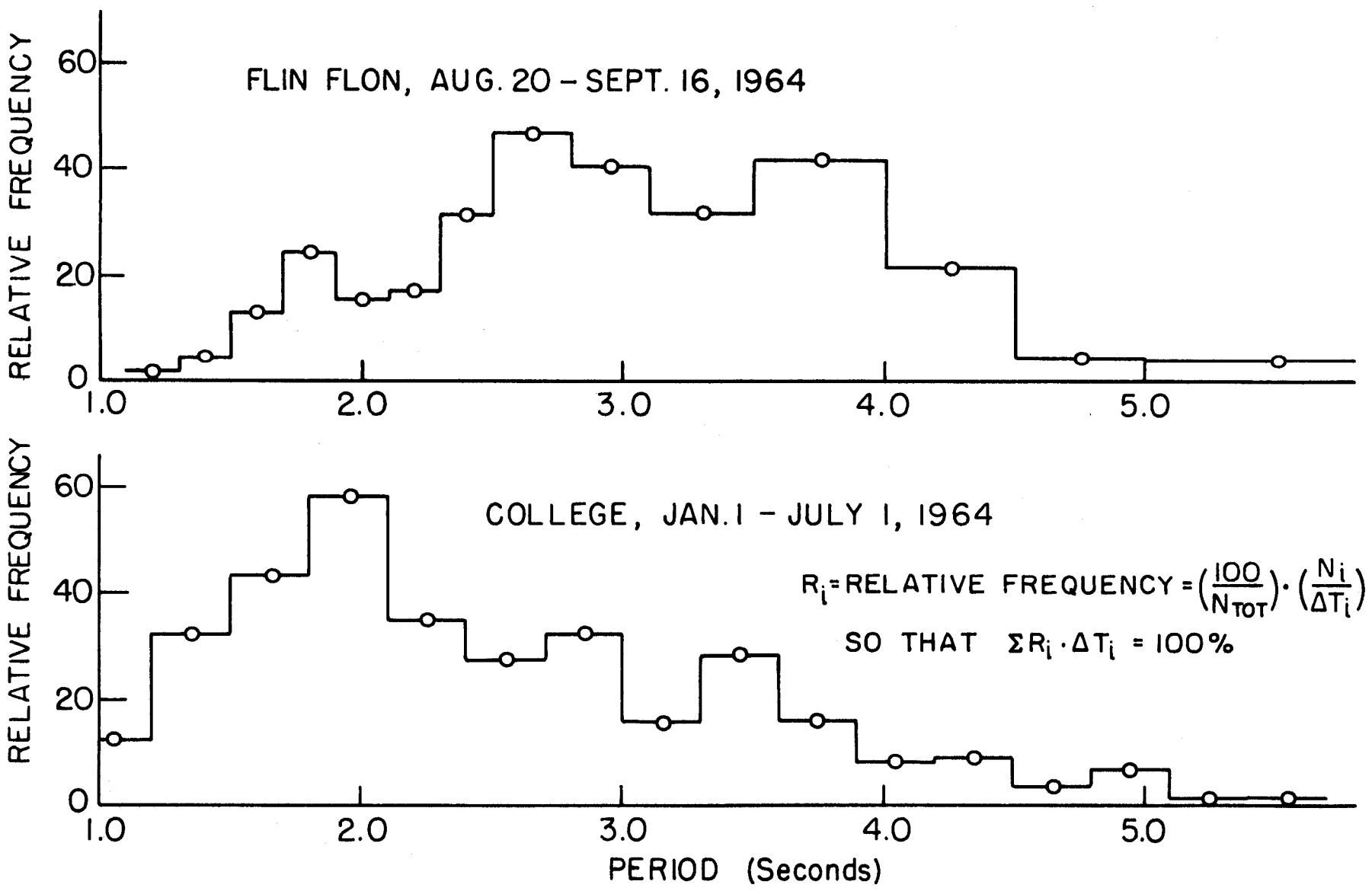

AMPLITUDE (Milligamma)
300
200
100
0
6
12
18
MAXIMUM AMPLITUDE FOR
10 MINUTE INTERVAL, PC-1 BAND
PEARL
PULSATIONS
1500
1000
500
0
COUNTS PER SECOND
TEN MINUTE AVERAGE
COUNTING RATE OF
15 - 20 KEV X-RAYS
FLIGHT 415
FLIN FLON, MANITOBA
SEPT. 8, 1964
6
12
18
EASTERN STANDARD TIME (Hours)

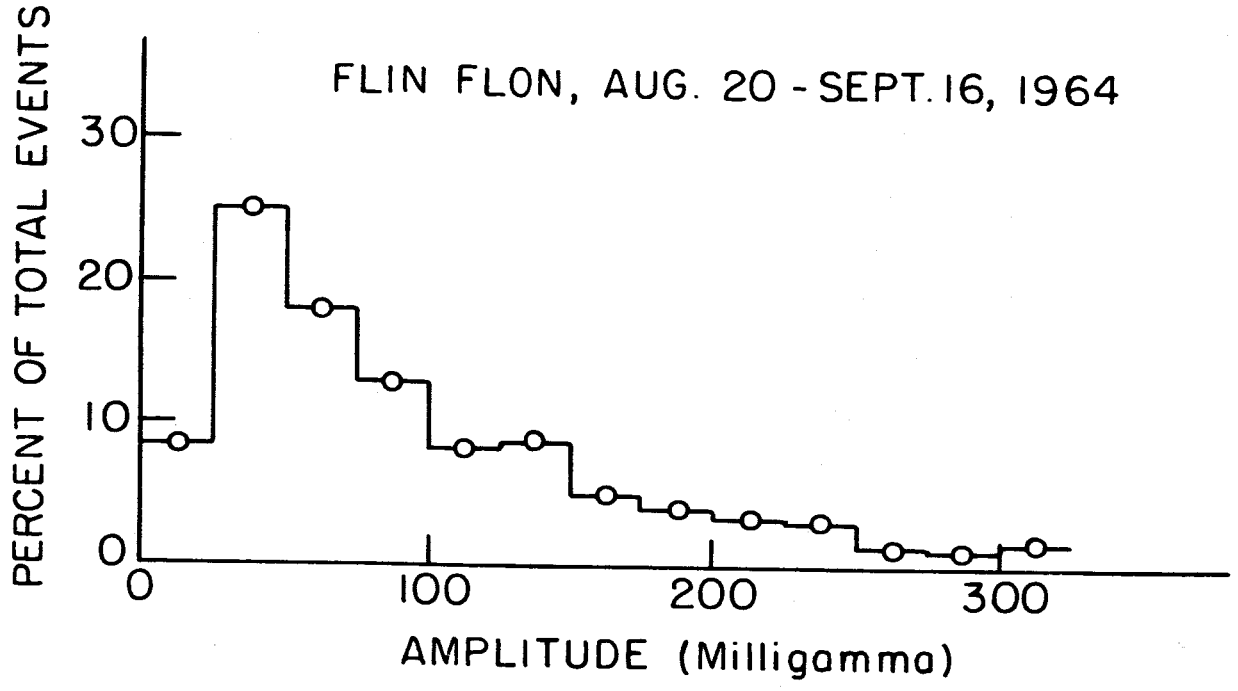

MAXIMUM AMPLITUDE IN ONE MINUTE INTERVALS
Pc - 1 BAND
RELATIVE AMPLITUDE
15
10
5
0
ONE MINUTE AVERAGE 10-15 KEV X-RAYS
FLIGHT 415 FLIN FLON
SEPT. 8, 1964
COUNTING RATE
800
600
400
200
0
1300
1330
1400
EASTERN STANDARD TIME

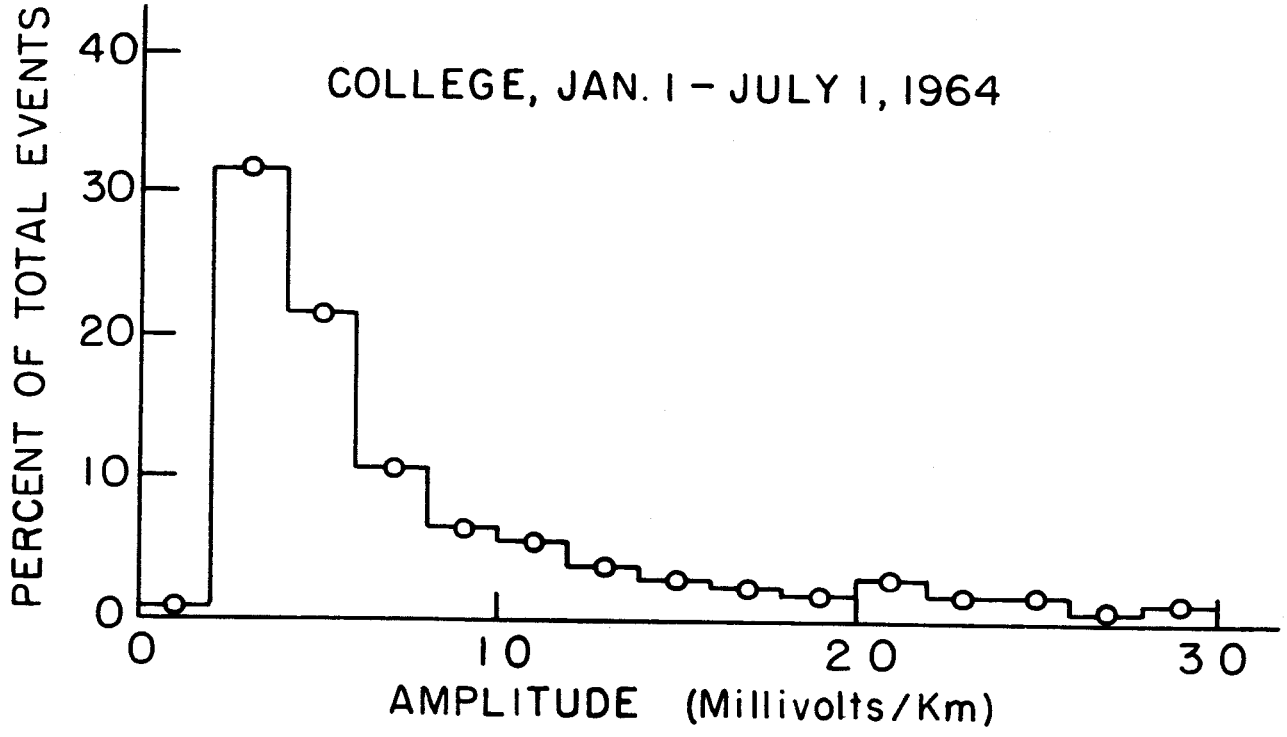

NUMBER OF OCCURRENCES
30
20
10
0
TOTAL HALF HOUR OCCURRENCES
PER DAY
COLLEGE
20
25
30
5
10
15
NUMBER OF OCCURRENCES
60
40
20
0
TOTAL TEN MINUTE OCCURRENCES
PER DAY
FLIN FLON
MISSING
DATA
20
25
30
5
10
15
MAGNETIC INDEX Ap
30
20
10
0
WORLD WIDE INDEX
OF MAGNETIC ACTIVITY
SUDDEN
COMMENCEMENT
20
25
30
5
10
15
AUG.
SEPT.

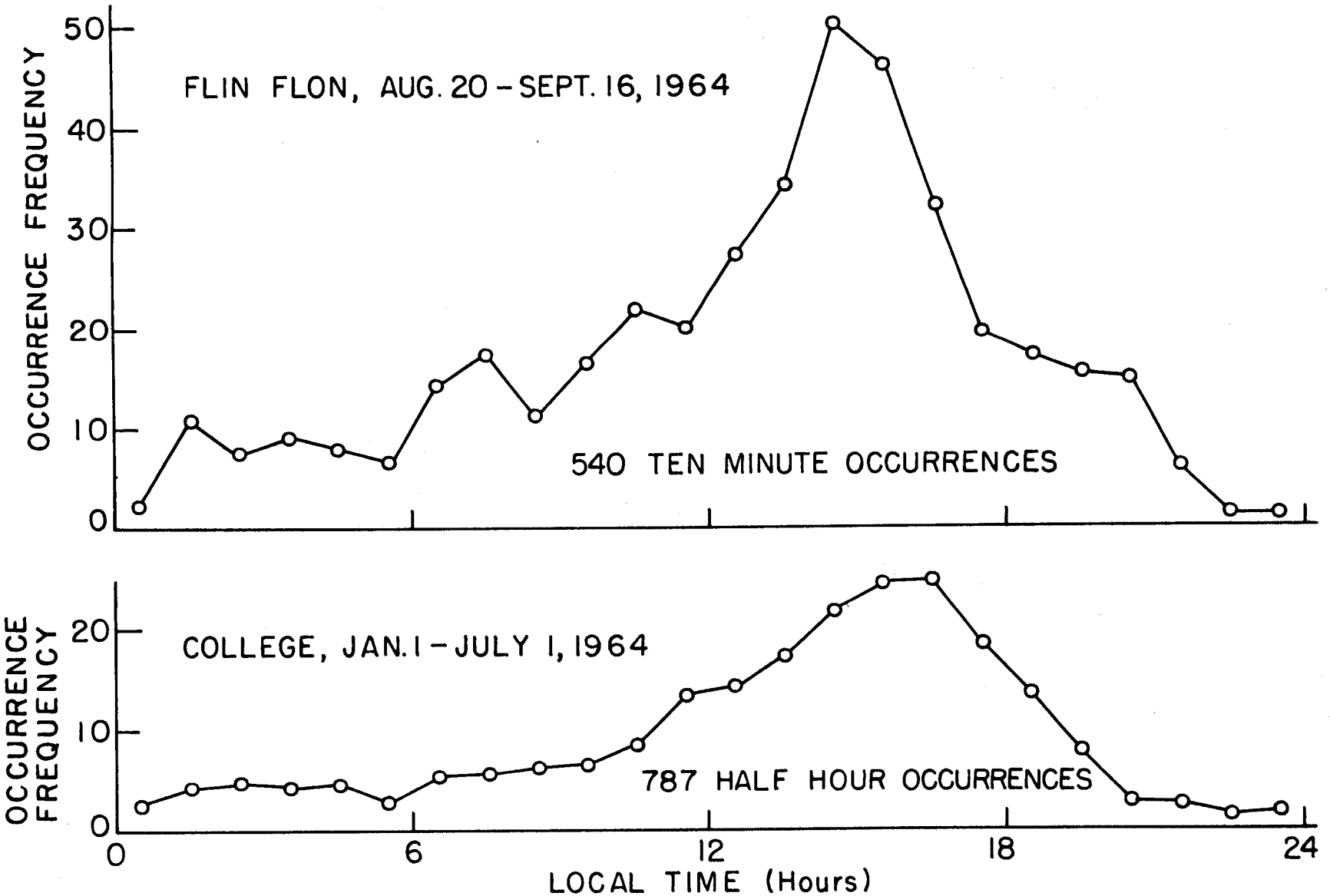

FLIN FLON, MANITOBA
SEPT. 6, 1964
PEARL EVENTS →
3.3, 2.4
1.5, 1.5, 1.7
4.0 2.0 2.0 2.0 4.0 4.0
H
AMPLITUDE (Milligamma)
400
200
0
0
6
12
18
CENTRAL STANDARD TIME

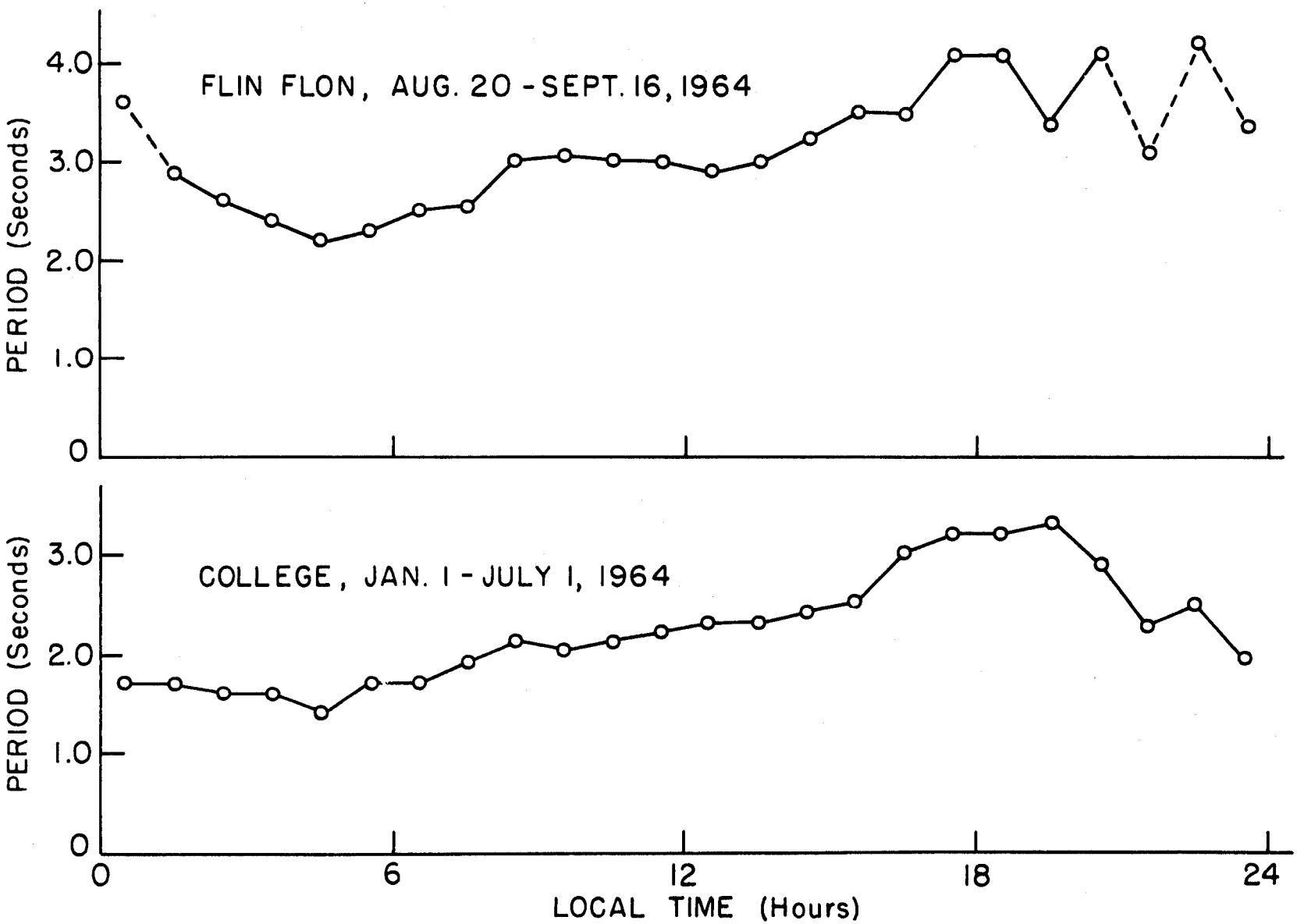

END OF MAGNETIC STORM
30
20
10
0
A_P INDEX
PRESTORM AVERAGE
60
40
20
0
DAILY OCCURRENCES
4.0
2.0
0
AVERAGE PERIOD (Seconds)
200
100
0
AVERAGE AMPLITUDE (Milligamma)
0
2
4
6
8
10
STORM TIME (DAYS)

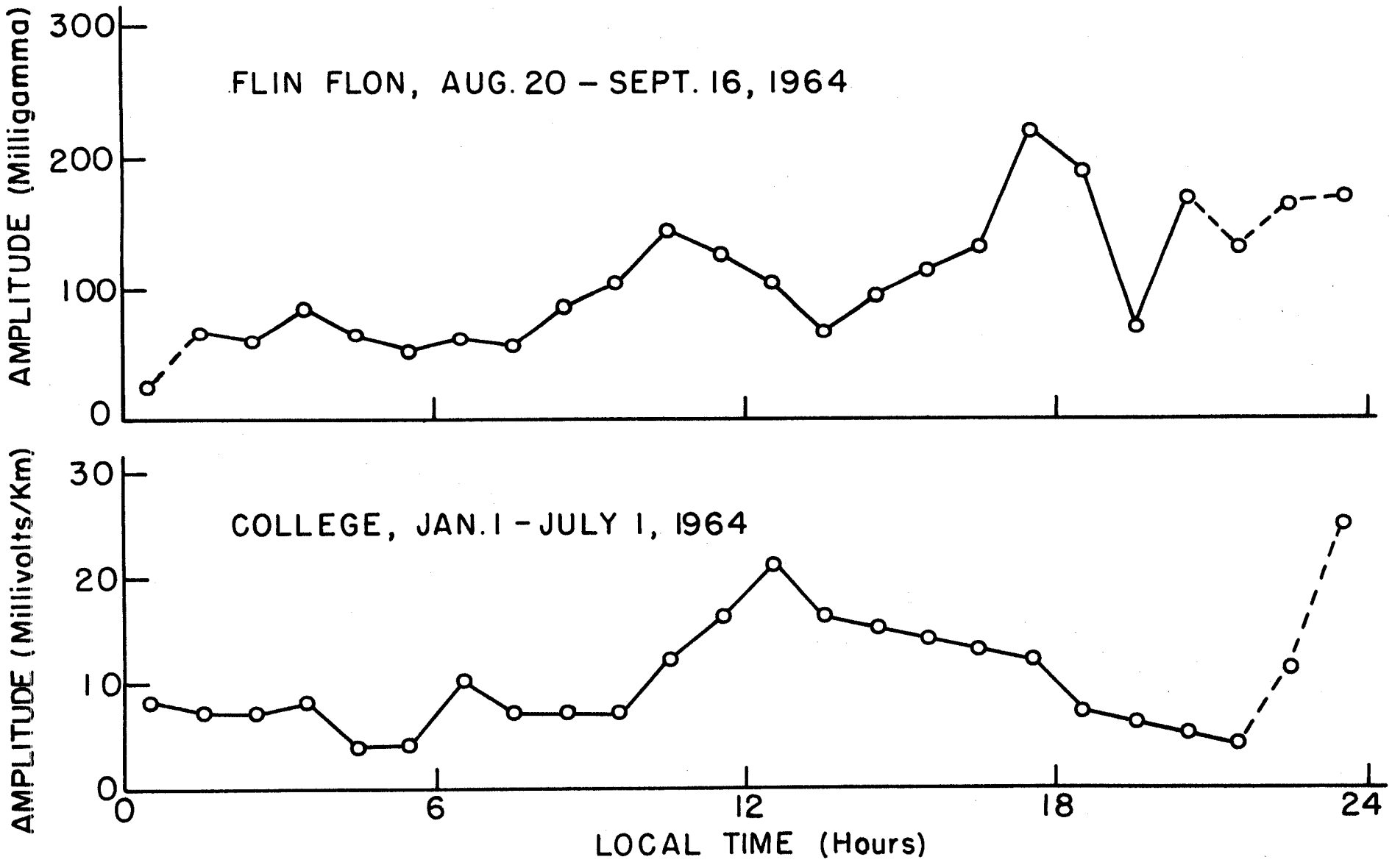

FLIN FLON, AUG. 20 – SEPT. 16, 1964
RELATIVE FREQUENCY
60
40
20
0
1.0
2.0
3.0
4.0
5.0
COLLEGE, JAN. 1 – JULY 1, 1964
R_i = RELATIVE FREQUENCY = $\left(\frac{100}{N_{TOT}}\right) \cdot \left(\frac{N_i}{\Delta T_i}\right)$
SO THAT $\Sigma R_i \cdot \Delta T_i = 100\%$
PERIOD (Seconds)

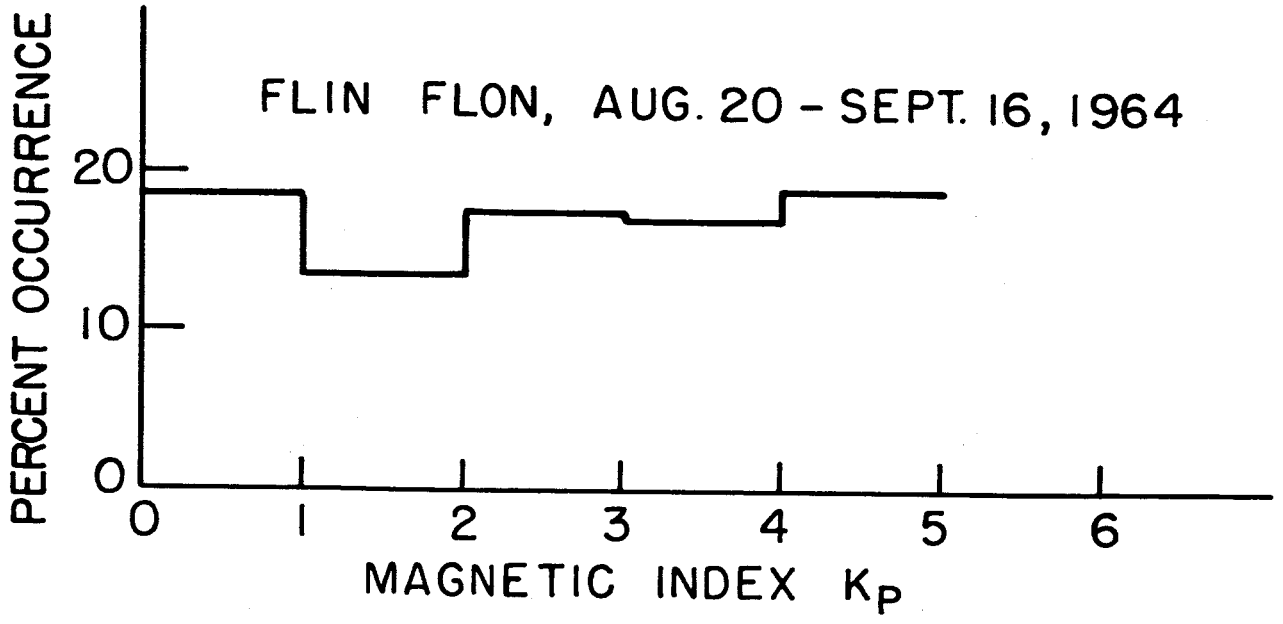

FLIN FLON, AUG. 20 - SEPT. 16, 1964
PERCENT OF TOTAL EVENTS
30
20
10
0
0
100
200
300
AMPLITUDE (Milligamma)

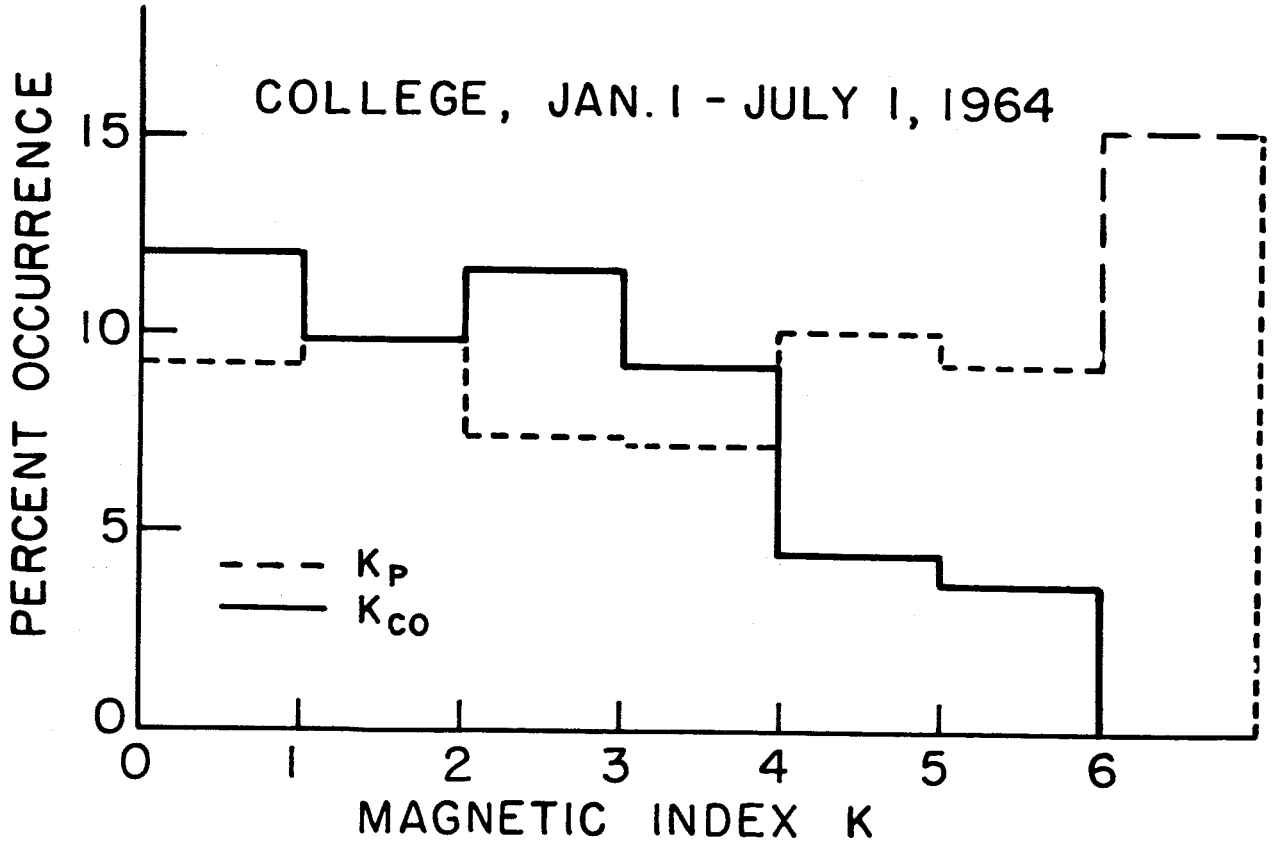

COLLEGE, JAN. 1 - JULY 1, 1964
PERCENT OF TOTAL EVENTS
40
30
20
10
0
0
10
20
30
AMPLITUDE (Millivolts/Km)

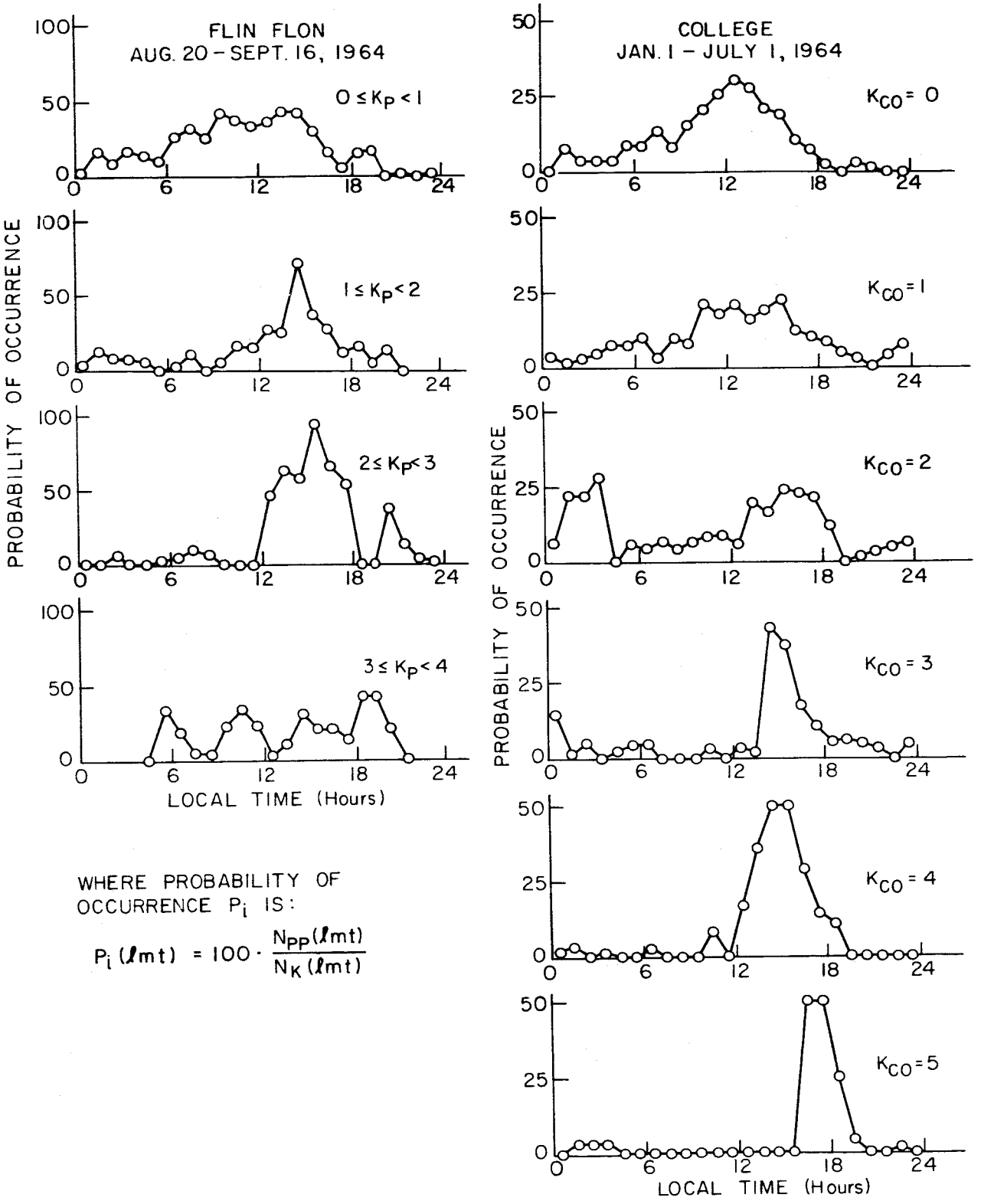

OCCURRENCE FREQUENCY
50
40
30
20
10
0
FLIN FLON, AUG. 20 - SEPT. 16, 1964
540 TEN MINUTE OCCURRENCES
OCCURRENCE FREQUENCY
20
10
0
COLLEGE, JAN. 1 - JULY 1, 1964
787 HALF HOUR OCCURRENCES
0
6
12
18
24
LOCAL TIME (Hours)


FLIN FLON, AUG. 20 - SEPT. 16, 1964
PERIOD (Seconds)
4.0
3.0
2.0
1.0
0
COLLEGE, JAN. 1 - JULY 1, 1964
PERIOD (Seconds)
3.0
2.0
1.0
0
0
6
12
18
24
LOCAL TIME (Hours)


FLIN FLON, AUG. 20 – SEPT. 16, 1964
AMPLITUDE (Milligamma)
300
200
100
0
COLLEGE, JAN. 1 – JULY 1, 1964
AMPLITUDE (Millivolts/Km)
30
20
10
0
0
6
12
18
24
LOCAL TIME (Hours)

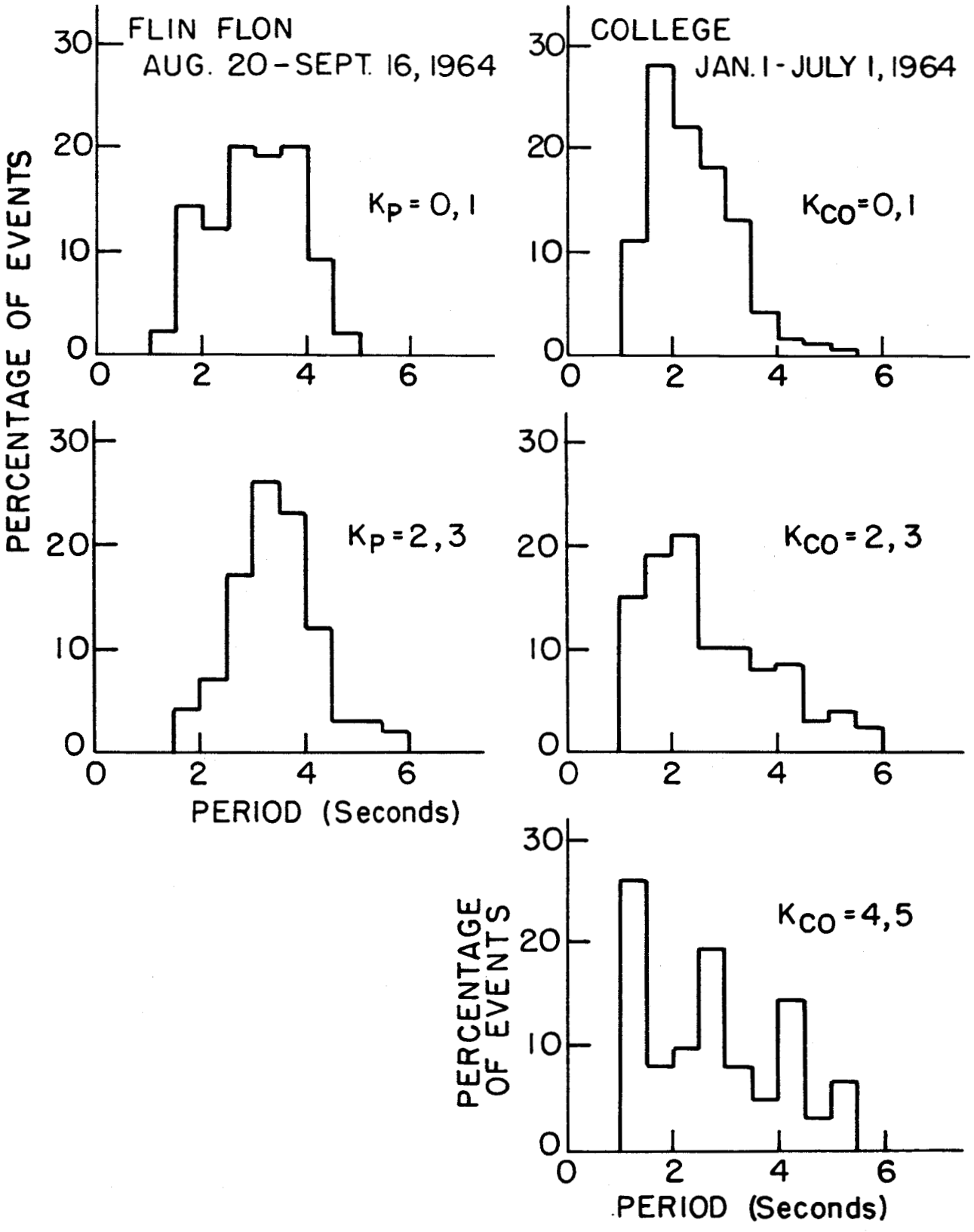

FLIN FLON, AUG. 20 - SEPT. 16, 1964
PERCENT OCCURRENCE
20
10
0
0
1
2
3
4
5
6
MAGNETIC INDEX K_P

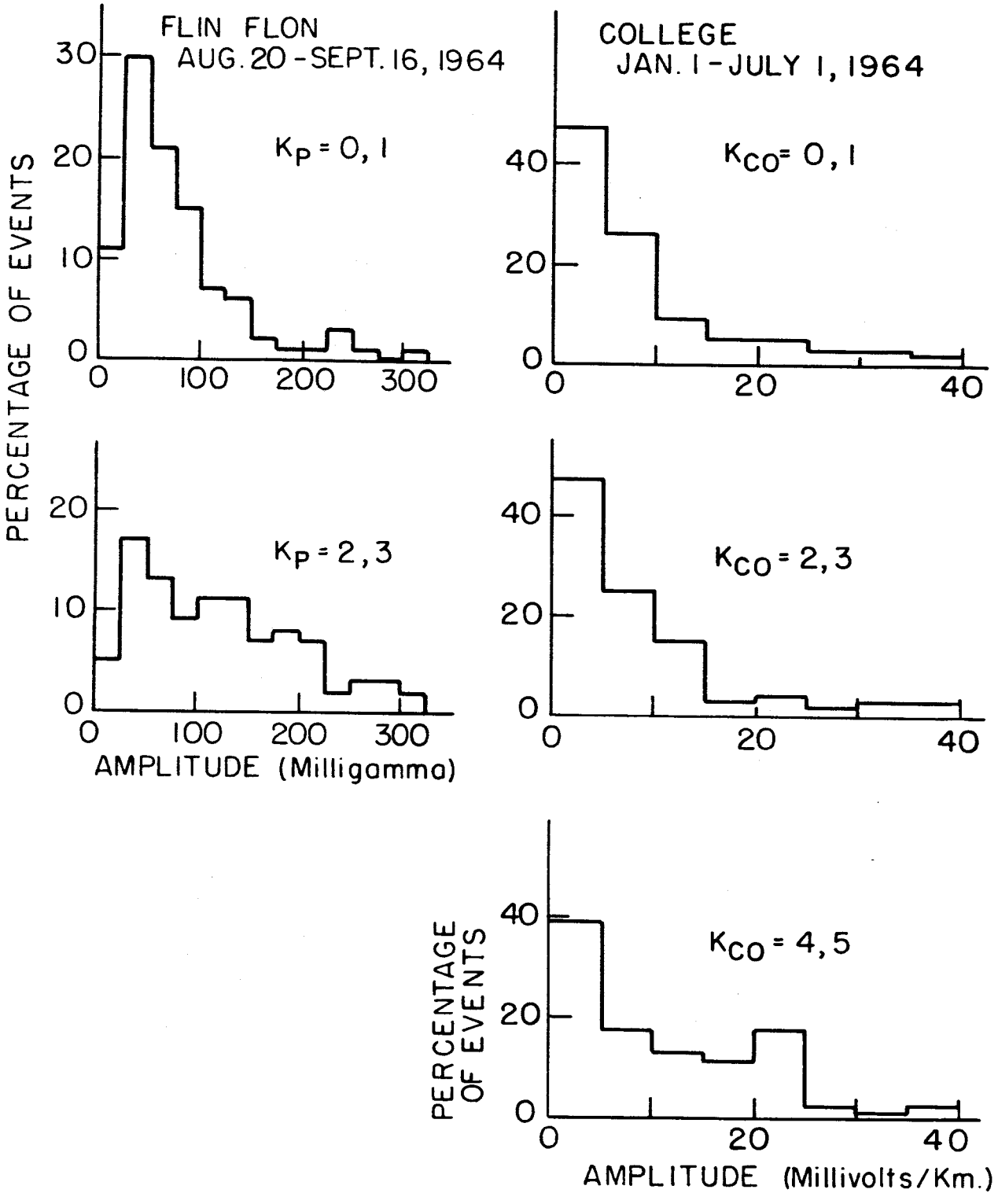

COLLEGE, JAN. 1 - JULY 1, 1964
PERCENT OCCURRENCE
15
10
5
0
K_P
K_{CO}
0
1
2
3
4
5
6
MAGNETIC INDEX K

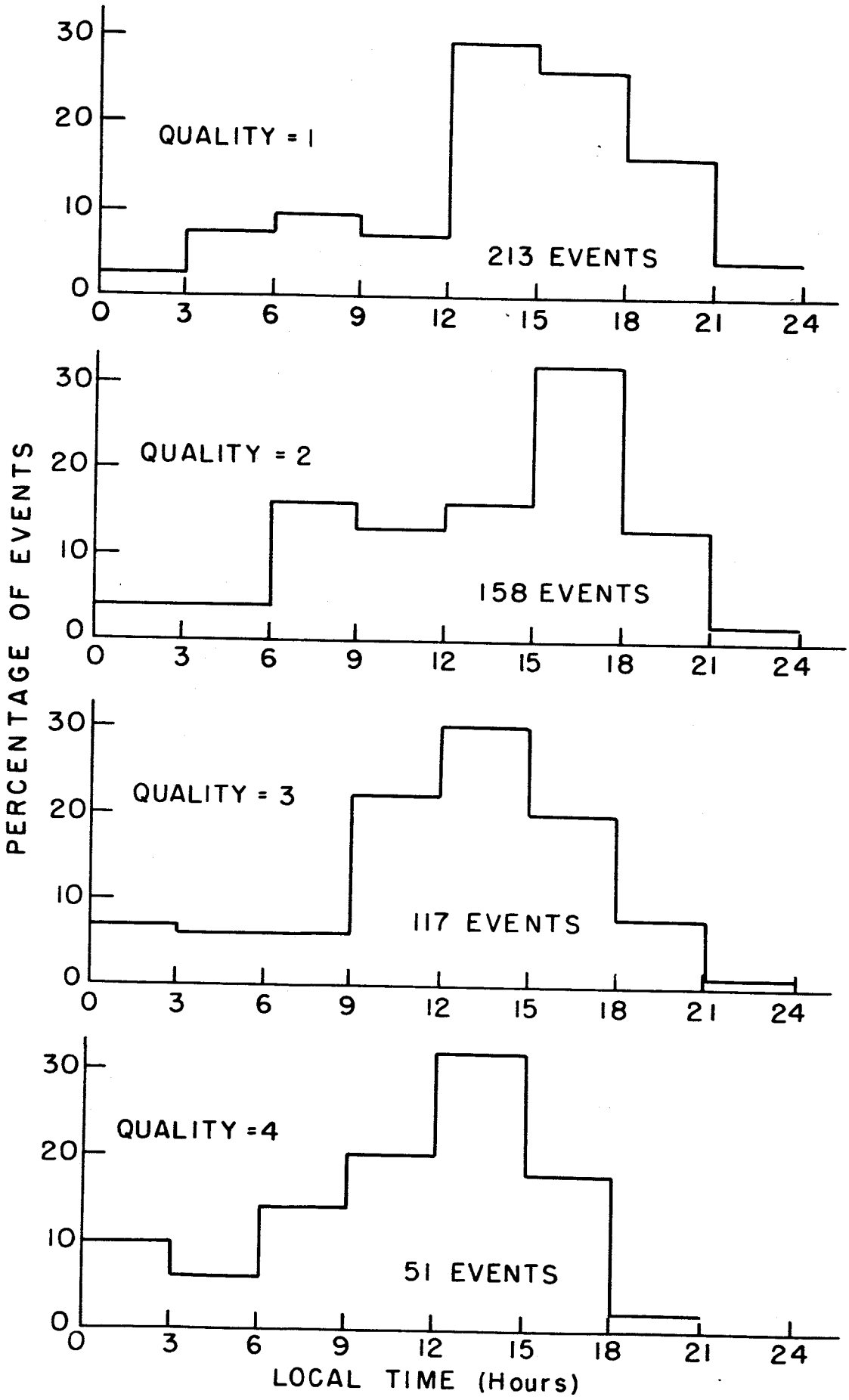


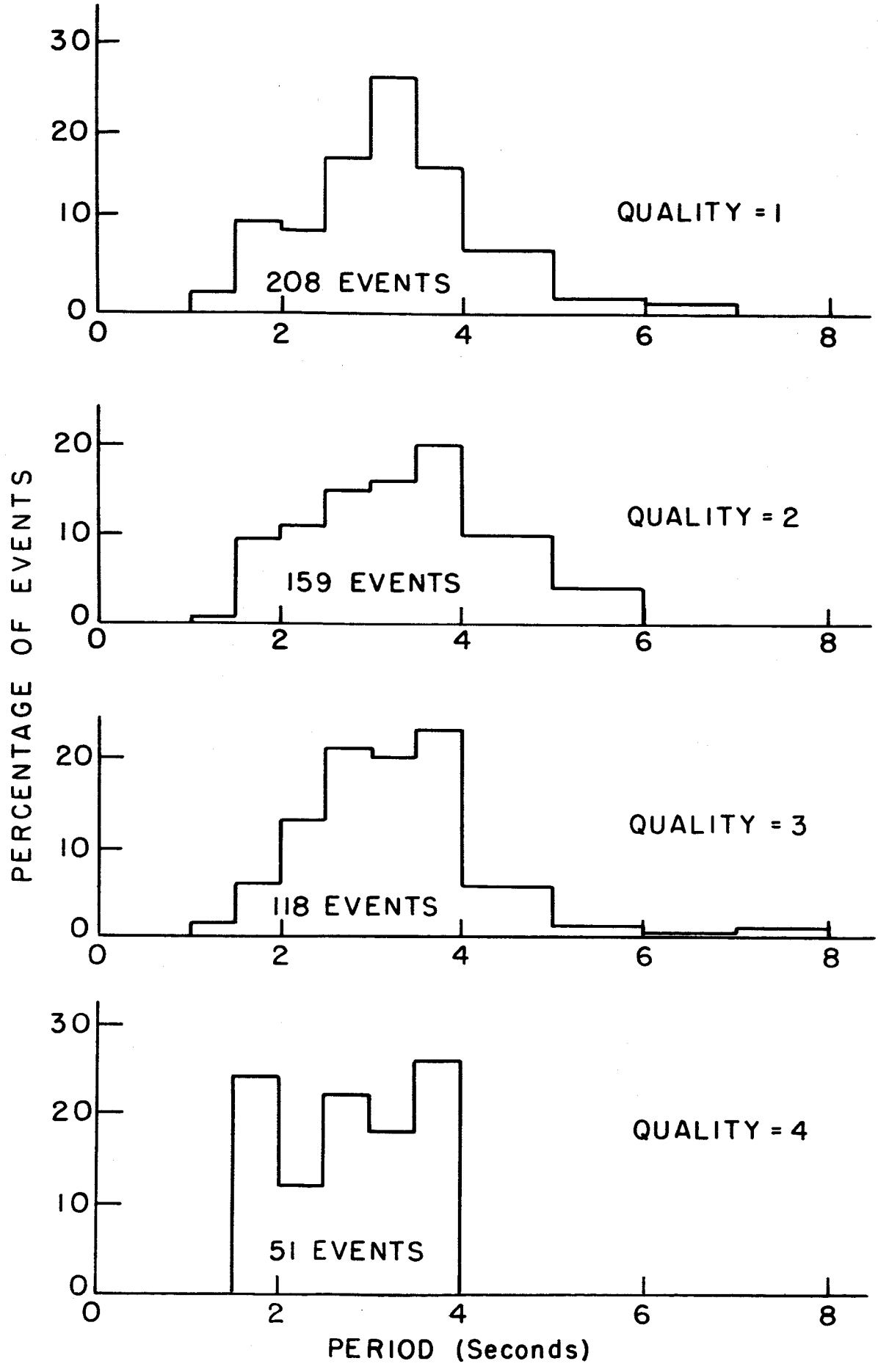
WHERE PROBABILITY OF OCCURRENCE P_i IS:

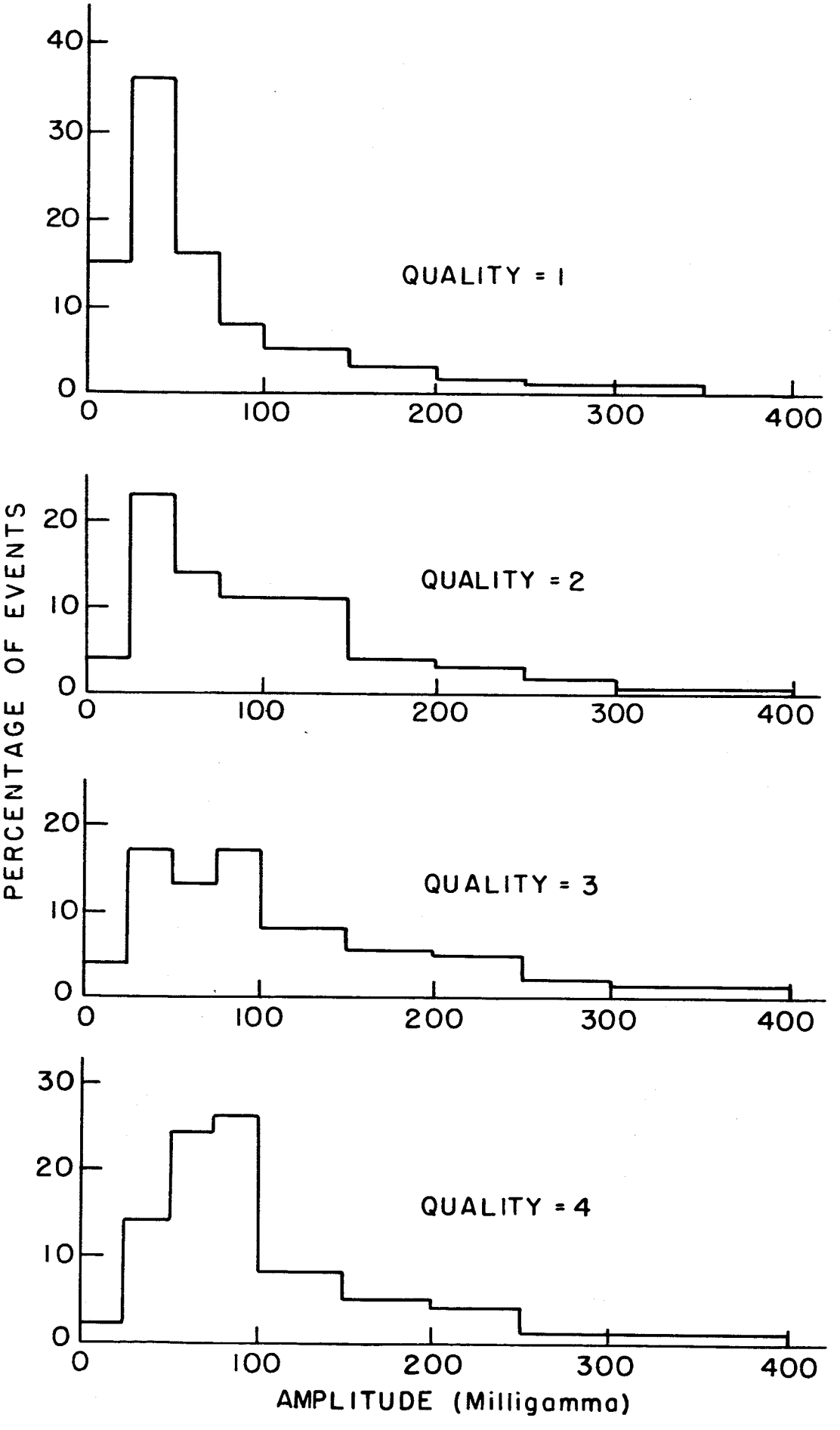
$$P_i(\ell mt) = 100 \cdot \frac{N_{PP}(\ell mt)}{N_K(\ell mt)}$$


FLIN FLON
AUG. 20 - SEPT. 16, 1964
COLLEGE
JAN. 1 - JULY 1, 1964
K_P = 0, 1
K_{CO} = 0, 1
K_P = 2, 3
K_{CO} = 2, 3
K_{CO} = 4, 5
PERCENTAGE OF EVENTS
PERIOD (Seconds)
0
10
20
30
0
2
4
6

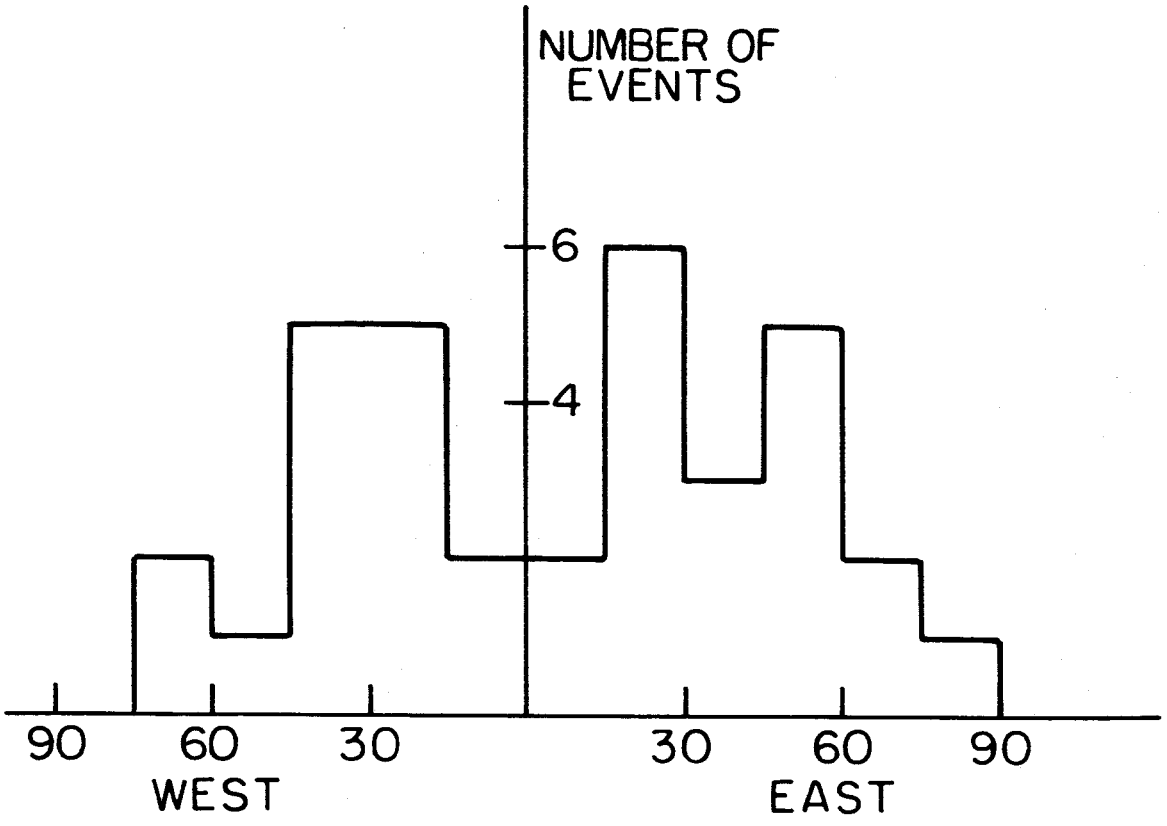

FLIN FLON
AUG. 20 - SEPT. 16, 1964
K_P = 0, 1
K_P = 2, 3
COLLEGE
JAN. 1 - JULY 1, 1964
K_{CO} = 0, 1
K_{CO} = 2, 3
K_{CO} = 4, 5
PERCENTAGE OF EVENTS
AMPLITUDE (Milligamma)
AMPLITUDE (Millivolts/Km.)


QUALITY = 1
213 EVENTS
QUALITY = 2
158 EVENTS
QUALITY = 3
117 EVENTS
QUALITY =4
51 EVENTS
PERCENTAGE OF EVENTS
LOCAL TIME (Hours)
0
10
20
30
0
3
6
9
12
15
18
21
24

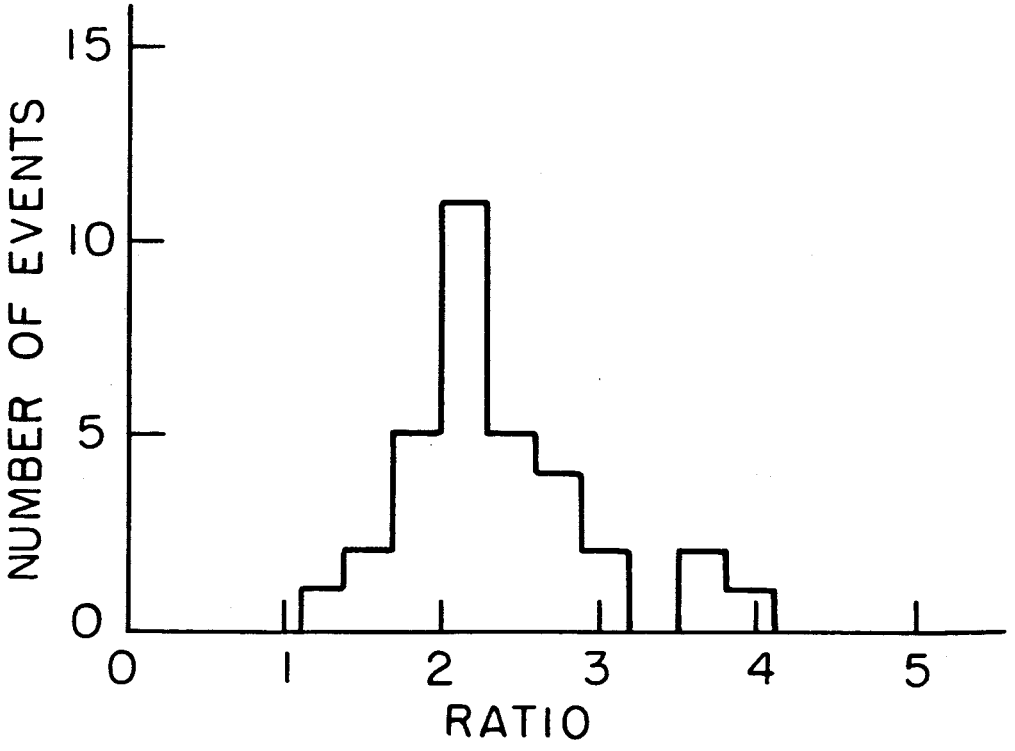

30
20
10
0
0
2
4
6
8
208 EVENTS
QUALITY = 1
20
10
0
159 EVENTS
QUALITY = 2
PERCENTAGE OF EVENTS
20
10
0
118 EVENTS
QUALITY = 3
30
20
10
0
51 EVENTS
QUALITY = 4
PERIOD (Seconds)

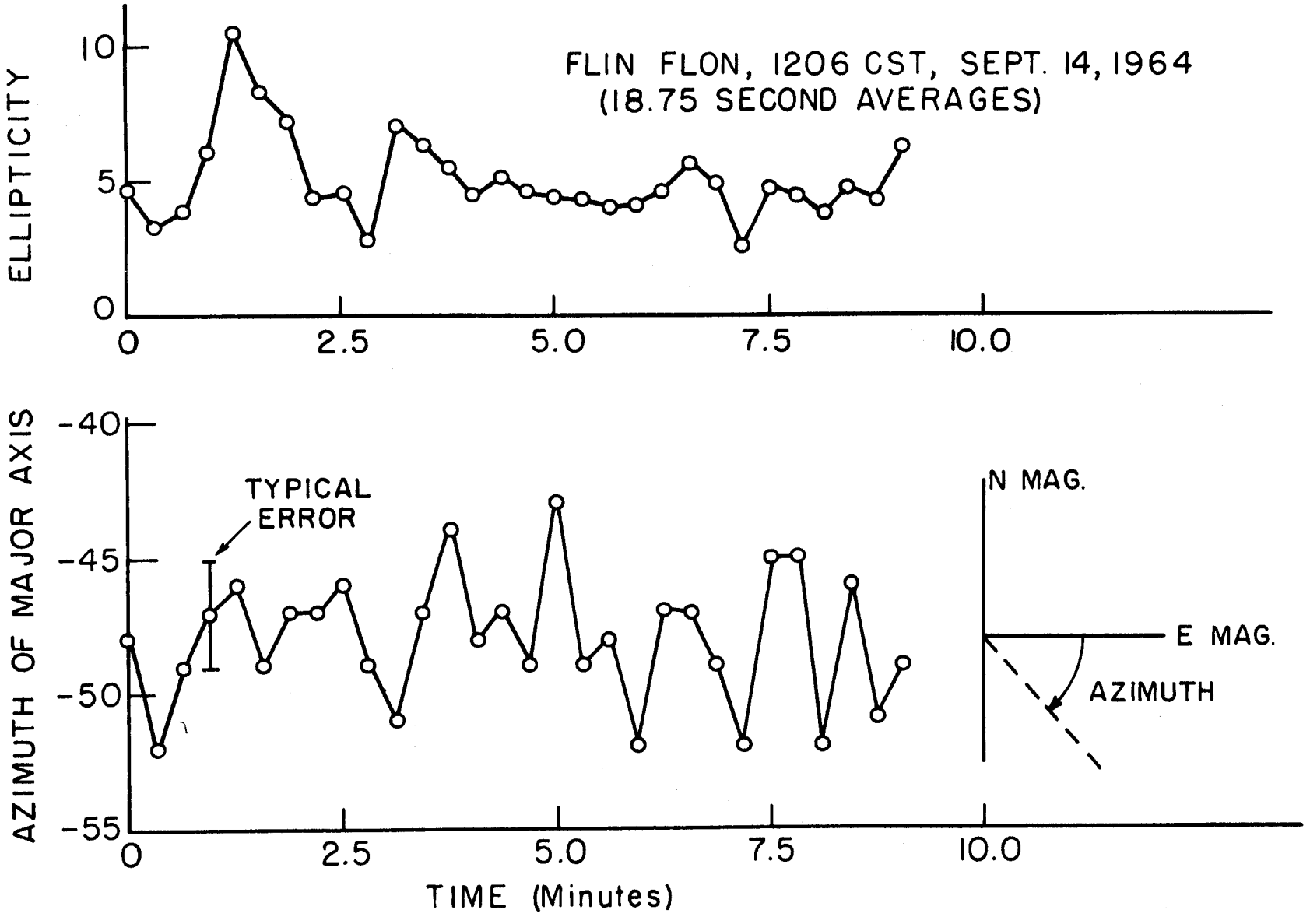

40
30
20
10
0
QUALITY = 1
0
100
200
300
400
PERCENTAGE OF EVENTS
20
10
0
QUALITY = 2
0
100
200
300
400
20
10
0
QUALITY = 3
0
100
200
300
400
30
20
10
0
QUALITY = 4
0
100
200
300
400
AMPLITUDE (Milligamma)

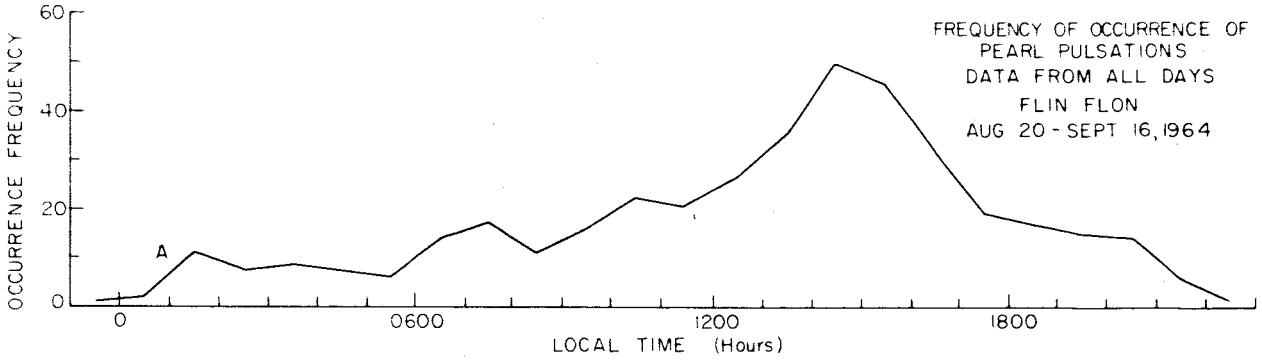
DISTRIBUTION OF AZIMUTHS

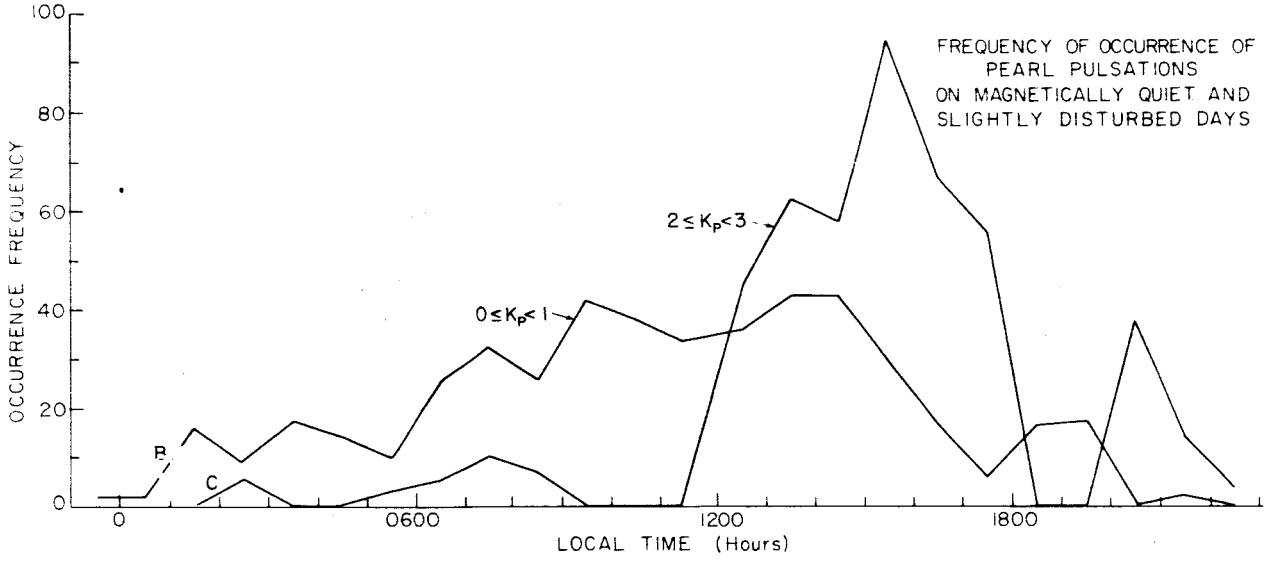


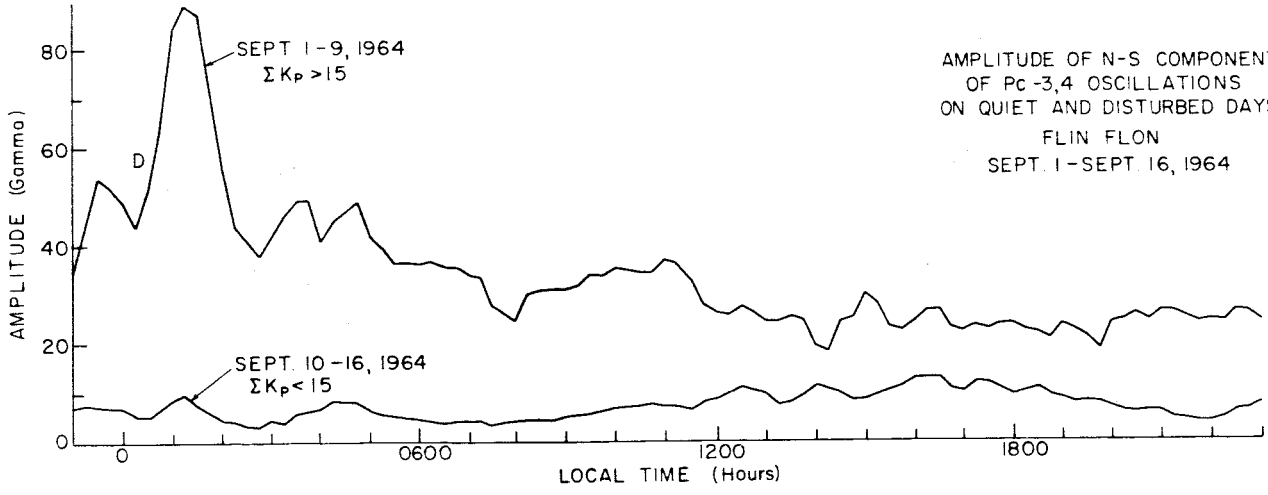
DISTRIBUTION OF MAJOR-MINOR AXIS RATIO




FLIN FLON, 1206 CST, SEPT. 14, 1964
(18.75 SECOND AVERAGES)
ELLIPTICITY
10
5
0
0
2.5
5.0
7.5
10.0
AZIMUTH OF MAJOR AXIS
-40
-45
-50
-55
TYPICAL
ERROR
N MAG.
E MAG.
AZIMUTH
0
2.5
5.0
7.5
10.0
TIME (Minutes)


FREQUENCY OF OCCURRENCE OF
PEARL PULSATIONS
DATA FROM ALL DAYS
FLIN FLON
AUG 20 - SEPT 16, 1964
OCCURRENCE FREQUENCY
60
40
20
0
A
0
0600
1200
1800
LOCAL TIME (Hours)


FREQUENCY OF OCCURRENCE OF
PEARL PULSATIONS
ON MAGNETICALLY QUIET AND
SLIGHTLY DISTURBED DAYS
OCCURRENCE FREQUENCY
100
80
60
40
20
0
2≤Kp<3
0≤Kp<1
B
C
0
0600
1200
1800
LOCAL TIME (Hours)


AMPLITUDE OF N-S COMPONENT
OF Pc -3,4 OSCILLATIONS
ON QUIET AND DISTURBED DAYS
FLIN FLON
SEPT. 1 - SEPT. 16, 1964
AMPLITUDE (Gamma)
80
60
40
20
0
SEPT. 1 - 9, 1964
ΣKp >15
D
SEPT. 10 - 16, 1964
ΣKp< 15
0
0600
1200
1800
LOCAL TIME (Hours)

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3. REPORT TITLE

Auroral Zone Pearl Pulsations

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical

5. AUTHOR(S) *(Last name, first name, initial)*

McPherron, R. L. and Ward, S. H.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research

13. ABSTRACT

An analysis has been made of Pc 1 band micropulsations observed in the auroral zone during one solar rotation at Flin Flon, Manitoba, August - September 1964. The Pc-1 band micropulsations were subdivided into Pearl Pulsations (PP), impulsive activity (IMP), and short irregular pulsations (SIP); this paper is concerned primarily with PP.

We have observed the following: (1) there is no correlation of PP with electron precipitation indicated by bremsstrahlung recorded at balloon altitude; (2) PP type activity occurs at the time of a sudden commencement and can have an hourly repetition of occurrence for five or six hours thereafter; (3) the K_p and A_p indices are too coarse for adequate representation of geomagnetically disturbed times when studying the dependence of PP occurrence on geomagnetic activity; (4) there may be a slight increase of PP period with increase in K; (5) PP have higher amplitudes when K values are higher; (6) Pc-3, 4 band activity may be used as a good predictor for PP occurrence, since, for days rated as disturbed by Pc 3-4 activity, there is an inverse correlation between PP and pc 3-4. For days rated as quiet by Pc-3, 4 activity, PP may occur at any time during the daylight hours; (7) PP are distributed throughout the daylight hours on quiet days while they tend to appear only within an hour or two of 1800 lmt on disturbed days; (8) observed polarization diagrams do not appear to be explained simply in terms of superimposed elliptically polarized waves as suggested by Pope (1964).

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Magnetic Micropulsations Pearl Pulsations Statistical Characteristics of Pearl Pulsations Geophysical Correlations of Pearl Pulsations						

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